TEHNOLOGIJE ČISTOG UGLJENA U STRATEGIJI RAZVOJA ELEKTROENERGETSKOG SUSTAVA

CLEAN COAL TECHNOLOGIES IN THE STRATEGIC DEVELOPMENT OF THE ELECTRICAL ENERGY SYSTEM

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Opisane su tehnologije čistog ugljena kojima je moguće smanjiti ili sasvim izbjeći emisije CO_2 i ostalih štetnih tvari u atmosferu. Zbog utjecaja na klimatske promjene posebna je pažnja posvećena mogućnostima odvajanja i skladištenja CO_2. Procijenjena je ekonomska isplativost takvih postupaka temeljem razvojnih projekata koji se provode u svijetu. Dan je prikaz suvremenih termoelektrana na kameni i smeđi ugljen koje su u fazi razvoja/izgradnje, a koriste tehnologije čistog ugljena. Napravljen je osvrt na Strategiju energetskog razvoja Republike Hrvatske do 2030. godine i utvrđeno da se sigurnost opskrbe električnom energijom u Republici Hrvatskoj može ostvariti samo oslanjanjem na raznorodne izvore primarne energije: plin, ugljen, nuklearnu energiju i obnovljive izvore. Udjele pojedinih energenata u proizvodnji električne energije treba neprekidno preispitivati uzimajući u obzir svjetska kretanja i vlastite razvojne mogućnosti.

Clean coal technologies are described, through which it is possible to reduce or completely eliminate emissions of CO_2 and other pollutants into the atmosphere. Due to the impact on climate change, particular attention has been devoted to the possibility of the capture and sequestration of CO_2. The profitability of such procedures has been evaluated, based upon development projects being conducted around the world. Modern stone coal-fired and brown coal-fired thermoelectric power plants using clean coal technology in the development/construction phase are presented. A review has been presented of the Energy sector development strategy of the Republic of Croatia for the period until the year 2030 and it is has been determined that the security of the electrical energy supply in the Republic of Croatia can only be achieved by relying upon primary energy sources: gas, coal, nuclear energy and renewable sources. The percentage of individual energy source in the production of electrical energy should be constantly reassessed, taking world trends and the country's developmental potentials into account.

Ključne riječi: geološko skladištenje CO_2, moderne ugljene termoelektrane, svjetsko tržište ugljena, tehnologije čistog ugljena

Key words: clean coal technologies, modern coal-fired thermoelectric power plants, sequestration of CO_2, world coal market

1 UVOD

Ugljen je u svijetu najizdašnije i široko rasprostranjeno fosilno gorivo. Otprilike 23 % potreba za primarnom energijom te 39 % za električnom energijom namiruje se iz ugljena. Međunarodna energetska agencija (IEA) očekuje povećanje potrošnje ugljena od 43 % u vremenu od 2000. do 2020. godine [1].

Izgaranjem ugljena proizvodi se i ispušta u atmosferu oko 9 milijardi tona CO_2, a 70 % od tog iznosa odnosi se na proizvodnju električne energije. Neke druge procjene govore da na proizvodnju električne energije otpada jedna trećina od ukupno preko 25 milijardi tona svjetskih emisija CO_2.

Nove tehnologije čistog ugljena razvijaju se s ciljem da se omogući korištenje golemih svjetskih rezervi ugljena bez doprinošenja globalnom zatopljenju. Budući da ima mnogo elektrana na ugljen čiji vijek trajanja istječe u bliskoj budućnosti, njihovom zamjenom otvara se prostor za proizvodnju čiste električne energije. Uz nuklearne elektrane i korištenje obnovljivih energetskih izvora, nada za čistu električnu energiju nazire se kroz tehnologije čistog ugljena u čije se istraživanje i razvoj ulažu golema sredstva i napor. Pojam čisti ugljen u užem smislu odnosi se na ugljen očišćen od primjesa. Pojam tehnologije čistog ugljena u ovom članku obuhvaća i postupke kojima se uz smanjenja emisije drugih štetnih plinova u atmosferu smanjuje i emisija CO_2

1 INTRODUCTION

Coal is the most abundant and widely distributed fossil fuel in the world. Approximately 23 % of primary energy needs and 39 % of electrical energy needs are met by coal. The International Energy Agency (IEA) anticipates a 43 % increase in coal consumption from the year 2000 to 2020 [1].

Coal combustion produces and releases into the atmosphere approximately 9 billion tons of CO_2, of which 70 % is from the production of electrical energy. Other estimates state that one third of the total 25 billion tons of CO_2.emissions in the world come from the generation of electrical energy.

New clean coal technologies are being developed with the goal of utilizing the enormous world coal reserves without contributing to global warming. Since there are many coal-fired power plants that will reach the end of their operational lifetimes in the near future, their replacement provides an opportunity for the production of clean electrical energy. Together with nuclear power plants and harnessing renewable energy sources, hope for clean electrical energy is seen through clean coal technologies, in which considerable funding and efforts are being invested for research and development. The concept of clean coal in the narrow sense refers to coal that has been cleansed of a variety of wastes. The concept of clean coal technology in this article also includes procedures for reducing the emissions of CO_2 and other harmful gases into the atmosphere.

2 UGLJEN

Ugljen je fosilno gorivo nastalo tijekom geološkog razvoja Zemlje. Izmjena organske tvari i njeno pretvaranje u ugljen (treset, lignit, smeđi ugljen, kameni ugljen, poluantracit i antracit, a u određenim slučajevima i u grafit), događa se pod utjecajem specifičnih bioloških, fizičko-kemijskih i geoloških čimbenika. Suštinu procesa ugljenifikacije (karbonifikacije), predstavlja progresivno obogaćivanje ugljikom i sve veće osiromašenje kisikom. Po nastanku ugljena mogu se klasificirati na humusne, sapropelne i liptobiolite [2], a primjenu u energetici nalaze humusni ugljeni. Oko 70 % termoenergetskih postrojenja loženih ugljenom upotrebljavaju kameni ugljen, a ostala koriste smeđi ugljen i lignit. Kameni ugljeni se dijele u tri podskupine [2]:

– plinski ugljeni sa sadržajem hlapljivih tvari 35 % – 50 %,
– srednji ugljeni sa sadržajem hlapljivih tvari 19 % – 35 %,
– mršavi ugljeni sa sadržajem hlapljivih tvari 10 % – 19 %.

Ovisno o vremenu nastanka i zemljopisnom podrijetlu, ugljeni nose karakteristike bitne za sposobnost skladištenje i izbor kotlovskog postrojenja.

2.1 Zalihe kamenog ugljena u svijetu

Procjenjuje se da postoji oko 1 000 milijardi tona registriranih zaliha ugljena u čitavom svijetu (slika 1).

2 COAL

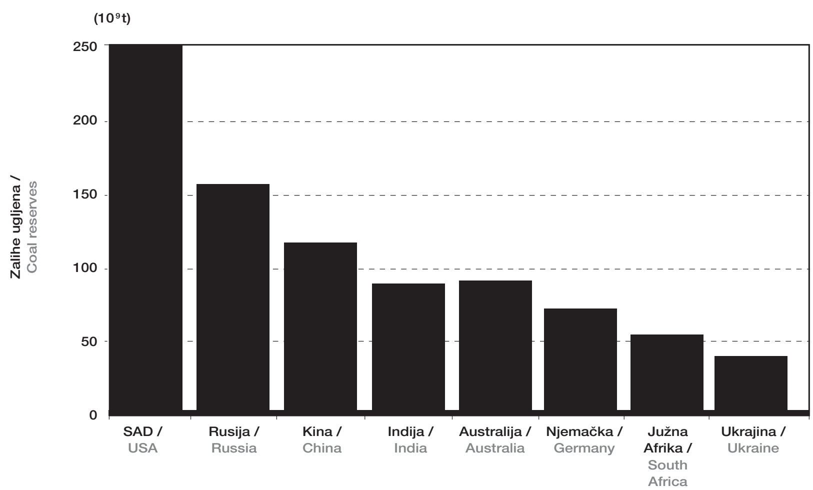
Coal is a fossil fuel that was formed during the geological development of the Earth. The replacement of organic substances and their transformation into coal (peat, lignite, brown coal, stone coal, semi-anthracite and anthracite, and graphite in certain cases) occurred under the influence of specific biological, physiochemical and geological factors. The essence of the process of carbonification is the progressive enrichment with carbon and the depletion of oxygen. According to origin, we can classify coal into humus, sapropelne and liptobiolite [2], and humus coals have applications in energetics. Approximately 70 % of all thermal coal-fired energy plants use stone coal, and the others use brown coal and lignite. We divide stone coal into three subgroups [2]:

– gas coals with 35 % – 50 % volatile matter,
– average coals with 19 % – 35 % volatile matter,
– meager coals with 10 % – 19 % volatile matter.

Depending upon the time and geography of origin, coals have characteristics essential for storage and the choice of boiler plants.

2.1 Stone coal reserves in the world

It is estimated that there are approximately 1000 billion tons of registered coal reserves throughout the world, Figure 1.



Slika 1
Zemlje s najvećim rezervama ugljena, 2003.
Figure 1
Countries with the largest coal reserves, 2003

Ugljen se može naći na svakom kontinentu, u više od 50 zemalja (tablica 1).

Coal can be found on every continent, in more than 50 countries, Table 1.

Tablica 1 – Rezerve ugljena s regionalnim udjelima [3]
Table 1 – Coal reserves according to region [3]

Regije / Regions	Rezerve ugljena s regionalnim udjelima (na kraju 2003. godine) / Coal reserves according to region (late 2003) (%)
Europa i Euroazija / Europe and Eurasia	36
Azija i Pacifik / Asia and the Pacific	30
Sjeverna Amerika / North America	26
Afrika / Africa	6
Južna i Centralna Amerika / South and Central America	2
Srednji Istok / Middle East	< 1

Procjenjuje se da ugljena ima dovoljno za sljedećih 200 godina [4], što bi se moglo još produljiti zbog brojnih razvojnih dostignuća:

– otkrića novih zaliha ugljena zahvaljujući postojećim i poboljšanim metodama istraživanja,
– dostignuća u tehnikama rudarenja, koje će omogućiti korištenje danas neisplativih zaliha.

2.2 Karakteristike kamenog ugljena koji se koristi u proizvodnji električne energije

Svojstva energetskog ugljena nisu standardizirana sa stanovišta energetskih postrojenja, ali se obično (poželjno) kreću u intervalima prema tablici 2. Granične vrijednosti su dobivene dugogodišnjom statističkom obradom energetskog ugljena na više desetaka termoenergetskih postrojenja.

It is estimated that there is enough coal for the next 200 years [4], which could still be extended due to numerous developmental achievements:

– the discovery of new coal reserves, owing to existing and improved prospecting methods,
– achievements in mining techniques, that permit the utilization of reserves that are presently not profitable.

2.2 Characteristics of the stone coal used in the production of electrical energy

The properties of coal used in energy production are not standardized from the aspect of energy plants but generally (desirably) range within the intervals presented in Table 2. The limit values have been obtained through many years of the statistical processing of the coal used in energy production at several dozen thermal energy plants.

Tablica 2 – Okvirne (granične) vrijednosti energetskog ugljena [5]
Table 2 – Approximate (limit) values of coal used in energy production [5]

Parametri ugljena / Coal parameters	Poželjna vrijednost / Desirable value	Granična vrijednost / Limit value
UGLJEN / COAL		
Toplinska vrijednost / Thermal value (MJ/ kg):		
– gornja / upper	što veća / as high as possible	–
– donja / lower	što veća / as high as possible	–
Tehnička analiza / Technical analysis:		
– ukupna vlaga (ds) / total moisture (ds) (%)	4 – 8	maksimalno / maximum 12
– površinska vlaga / surface moisture (%)		
– sadržaj pepela (ps) / ash content (cdc) (%)	što manji / as low as possible	maksimalno / maximum 15 – 20
– sadržaj hlapljivih tvari (ps) / volatile matter content (cdc) (%)	20 – 35	minimalno / minimum 20
– ukupni sumpor / total sulfur (%)	što manji / as low as possible	0,5 – 1
– oblici sumpora / sulfur forms		
Elementarna analiza / Elementary analysis:		
– dušik (gt) / nitrogen (cm) (%)	što manji / as low as possible	0,8 – 1,1
– klor (ps) / chlorine (cdc) (%)	što manji / as low as possible	maksimalno / maximum 0,1 – 0,3
– kisik / oxygen (%)		
– vodik / hydrogen (%)		
– hardgroverov indeks meljivosti / Hardgrove Grindability Index (HGI)	što veći / as high as possible	minimalno / minimum
– maksimalna veličina komada / maximum piece size (mm)	50	45 – 35
– udio čestica manjih od 0,5 mm / percentage of particles smaller than 0,5 mm (%)	maksimalno / maximum 15	40 – 130
PEPEO / ASH		
Analiza pepela (težinski udjeli) / Ash analysis (by weight) (%):		
– silicijev dioksid / silicon dioxide SiO_2		45 – 75
– aluminijev dioksid / aluminum dioxide Al_2O_3		15 – 35
– titanov oksid / titantium oxide TiO_2		0,4 – 2,2
– željezni oksid / ferrous oxide Fe_2O_3		1 – 12
– kalcijev oksid / calcium oxide CaO		0,1 – 2,3
– magnezijev oksid / magnesium oxide MgO		0,2 – 1,4
– kalijev oksid / potassium oxide K_2O		0,8 – 2,6
– natrijev oksid / sodium oxide Na_2O		0,1 – 0,9
– sulfid / sulfide FeS_2		0,1 – 1,6
– fosforov pentoksid / phosphoric pentoxide P_2O_5		0,1 – 1,5
Karakteristične temperature pepela / Characteristic ash temperatures:		
– t1 – početna deformacija / initial deformation (°C)	što veća / as high as possible	> 1 075
– t2 – točka omekšavanja / softening point (°C)	što veća / as high as possible	> 1 150
– t3 – točka taljenja / melting point (°C)	što veća / as high as possible	> 1 180
– t4 – točka tečenja / liquification point (°C)	što veća / as high as possible	> 1 225
Indeks bubrenja / Blistering index	što manji / as low as possible	maksimalno / maximum 5

ds – ugljen u dostavnom stanju / ds – coal in delivered state,
ps – potpuno suh ugljen (bez vlage) / cdc – completely dry coal (without moisture),
gt – goriva tvar (bez pepela i vlage) / cm – combustible matter (without ash and moisture)

Nabava na svjetskom tržištu onemogućava nabavu ugljena s istim tehničko-tehnološkim parametrima, pa postrojenja, a time i skladišta, moraju biti prilagođena za prijam i uporabu različitih vrsta ugljena. Uporaba različitih vrsta ugljena traži miješanje ugljena radi dobivanja optimalnih karakteristika za određeno termoenergetsko postrojenje.

Nepostojanje svjetskog standarda zahtijeva poznavanje više standarda zemalja velikih uvoznica ili proizvođača ugljena. Najrašireniji standardi su ASTM, AS, BS, DIN i ISO.

2.3 Zemlje uvoznice/izvoznice kamenog ugljena

Međunarodna trgovina ugljenom naglo raste (tablica 3).

Procurement on the world market makes it impossible to purchase coal with uniform technical/technological parameters. Therefore, plants and storage facilities must be adapted to receive and use various types of coal. The use of various types of coal requires the mixing of coal in order to obtain the optimal characteristics for a particular thermoelectric plant.

The absence of a worldwide standard requires familiarity with the many standards of the major coal importing or producing countries. The most widely used standards are ASTM, AS, BS, DIN and ISO.

2.3 Stone coal importing/exporting countries

The international coal trade is growing rapidly (Table 3).

Tablica 3 – Ukupna svjetska trgovina kamenim ugljenom
Table 3 – Total world commerce in stone coal

Godina / Year	Ugljen za energiju / Coal for energy (Mt)	Ugljen za koksiranje / Coal for coking (Mt)	Ukupno / Total (Mt)
1991.	225	179	404
1996.	294	194	488
2000.	381	192	573

Trenutačno se proizvodi više od 4 000 Mt/god, što je porast od 38 % tijekom posljednjih 20 godina. Proizvodnja ugljena je najbrže rasla u Aziji, dok je u Europi došlo do smanjenja.

Currently over 4 000 Mt/year are produced, which is an increase of 38 % during the past 20 years. Coal production is growing the most quickly in Asia, while in Europe there has been a decrease.

Tablica 4 – Najveći proizvođači ugljena (2003.) [6]
Table 4 – Largest coal producers (2003) [6]

Zemlja / Country	Količina ugljena / Quantity of coal (Mt)
Kina / China	1 500
SAD / USA	900
Indija / India	320
Rusija / Russia	280
Australija / Australia	250
Južna Afrika / South Africa	240
Indonezija / Indonesia	100
Poljska / Poland	90
Kazahstan / Kazakhstan	80
Ukrajina / Ukraine	60

Najveće tržište ugljena je Azija, u kojoj se trenutačno troši preko 50 % globalne potrošnje ugljena.

The largest market for coal is Asia, with over 50 % of the global coal consumption.

Oko 16 % globalne proizvodnje kamenog ugljena (više od 750 milijuna tona) kupuje se na međunarodnom tržištu, pri čemu ugljen za termoelektrane čini većinu te trgovine (smatra se sigurnim i pouzdanim gorivom). Najveći svjetski uvoznik ugljena za termoelektrane je Japan (97,1 Mt u 2004. godini, ostalo je koksni ugljen za proizvodnju čelika), gdje se 28 % električne energije proizvodi iz ugljena. Danska, veliki zagovarač obnovljivih izvora energije, u 2004. godini je 46 % električne energije proizvela iz ugljena.

Approximately 16 % of the global production of stone coal (over 750 million tons) is purchased on the international market. Coal for thermal power plants comprises the majority of this commerce (it is considered a safe and reliable fuel). The biggest world importer of coal for thermal power plants is Japan (97,1 Mt in the year 2004, the remainder is coke for steel manufacture), where 28 % of the electrical energy is produced from coal. Denmark, a great advocate of renewable energy sources, produced 46 % of its electrical energy in the year 2004 from coal.

Neki tradicionalni proizvođači ugljena (Njemačka, Velika Britanija) smanjuju subvencije svom skupom ugljenu i tako postupno smanjuju njegovu proizvodnju u korist uvoznog ugljena.

Some traditional coal producers (Germany, Great Britain) are reducing subsidies for their expensive coal and thus are gradually reducing its production in favor of imported coal.

Tablica 5 – Zemlje glavni uvoznici ugljena [6]
Table 5 – Main coal importing countries [6]

Glavni uvoznici ugljena u 2003. godini / Main coal importers in the year 2003	Količina uvezenog ugljena / Quantity of imported coal (Mt)
Japan / Japan	162
Republika Koreja / Republic of Korea	72
Kineski Taipei / Chinese Taipei	54
Njemačka / Germany	35
Velika Britanija / Great Britain	32
Rusija / Russia	24
Indija / India	24
SAD / USA	23
Nizozemska / Netherlands	22
Španjolska / Spain	22

Ugljen za proizvodnju električne energije predstavlja osnovni energetski resurs na kojemu se temelji razvoj gospodarstva mnogih zemalja (tablica 6).

Coal for the production of electrical energy represents a basic energy resource, upon which the economic development of many countries is based, Table 6.

Tablica 6 – Proizvodnja električne energije iz ugljena (2000.)
Table 6 – The production of electrical energy from coal (2000)

Zemlja / Country	Udio u proizvodnji / The production share (%)
Poljska / Poland	96
Južna Afrika / South Africa	90
Australija / Australia	84
Kina / China	80
Češka / Czech Republic	71
Grčka / Greece	69
Indija / India	66
SAD / USA	56
Danska / Denmark	52
Njemačka / Germany	51
Nizozemska / Netherlands	42
EU (1999.) / EU (1999)	25

2.4 Transport ugljena

Transport ugljena do potrošača ovisan je o udaljenosti. Na malim udaljenostima ugljen se transportira transportnim trakama ili kamionima. Alternativno se na manjim udaljenostima koristi hidrotransport. Sitni se ugljen pomiješan s vodom transportira u cijevima kao smjesa (pulpa). Željeznički transport se rabi na većim udaljenostima, obično na tržištu jedne zemlje. Riječni transport je najjeftiniji i koristi se uvijek kad za to postoje uvjeti.

U međunarodnoj trgovini obično se koristi transport brodovima u rasponima od Handymax (40 000 do 60 000 DWT) i Panamax (oko 60 000 do 80 000 DWT) do velikih Capesize brodova (više od 80 000 DWT). Oko 90 % međunarodne trgovine odvija se morskim putem.

2.5 Sigurnost opskrbe

Tržište ugljena je veliko, s mnogo različitih proizvođača i potrošača na svakom kontinentu. Zalihe ugljena nisu koncentrirane u jednom području, što bi potrošače moglo učiniti ovisnim o sigurnosti zaliha i stabilnosti jedne regije. Mnoge se zemlje oslanjaju na vlastite zalihe ugljena, kao Kina, SAD, Indija, Australija i Južna Afrika. Ostale zemlje uvoze ugljen iz više zemalja, uzimajući onaj koji je trenutačno dostupniji. Opskrba ugljenom je sigurna zbog sljedećeg:

– zalihe ugljena su velike i bit će dostupne tijekom predvidive budućnosti,

2.4 Coal transport

The transport of coal to the consumer depends upon the distance. For a short distance, it is transported on tracks or trucks. Alternatively, hydrotransport is used for short distances. Pulverized coal mixed with water is transported in pipes as slurry. Railroad transport is used for large distances, generally for the market of a country. River transport is the least expensive and is always used when the prerequisites are present.

In international commerce, transport ships are generally used ranging from Handymax (40 000 to 60 000 deadweight tonnage (DWT) and Panamax (approximately 60 000 to 80 000 DWT) to large Capesize ships (over 80 000 DWT). Approximately 90 % of international commerce is by sea.

2.5 The security of supply

The coal market is large, with many different producers and consumers on every continent. Coal reserves are not concentrated in a single region, which could make consumers dependent upon the security of reserves and the stability of a region. Many countries rely upon their own coal reserves, such as China, the USA, India, Australia and South Africa. Other countries import coal from several countries, taking what is currently the most accessible. The coal supply is secure for the following reasons:

– coal reserves are large and will be accessible during the foreseeable future,

- ugljen je dostupan iz više izvora na dobro opskrbljenom svjetskom tržištu,
- ugljen se može jednostavno skladištiti u elektranama,
- proizvodnja električne energije na bazi ugljena nije ovisna o vremenu,
- za ugljen nisu potrebni posebni transportni putovi,
- transportne putove dostave ugljena nije potrebno štititi.

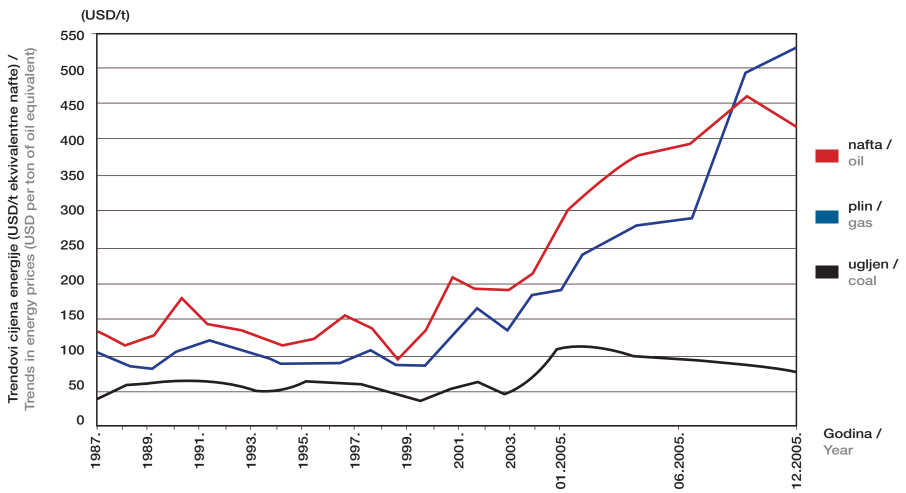
- coal is available from several sources on the well-stocked world market,
- coal can be simply stored in electrical power plants,
- the coal-based production of electrical energy is not dependent on the weather,
- special transport routes are not needed for coal,
- the transport routes for coal delivery do not need to be protected.

2.6 Dosadašnje kretanje cijena ugljena na svjetskom tržištu i trendovi rasta cijena

Predmet međunarodne trgovine isključivo je kameni ugljen. Manje kvalitetni ugljeni (smeđi i lignit) nisu predmet međunarodne trgovine, ali se koriste u zemljama proizvođačima. Interesantno je pratiti kretanje cijena glavnih primarnih energenata na svjetskom tržištu u dužem vremenskom razdoblju (slika 2). Cijene ugljena su samo donekle pratile promjene cijene nafte i plina i uglavnom su bile stabilne, s tendencijom zadržavanja stabilnosti i u budućnosti. Ukupna trgovina ugljenom prelazi vrijednost od 25 milijardi USD (2003.).

2.6 Trends to date in coal prices on the world market and rising prices

Stone coal is the only coal involved in international commerce. Lower quality coals (brown coal and lignite) are not traded internationally but are used in the countries of the producers. It is interesting to follow the trends in the prices of the main primary energy sources on the world market over a long period of time, Figure 2. Coal prices have only somewhat followed changes in oil and gas prices, and generally were stable, with a tendency to maintain stability in the future. The total coal trade exceeds USD 25 billion (2003).



Slika 2
Kretanje cijena plina, nafte i kamenog ugljena u svijetu
Figure 2
Trends in the prices of gas, oil and stone coal in the world

3 ELEKTRIČNA ENERGIJA

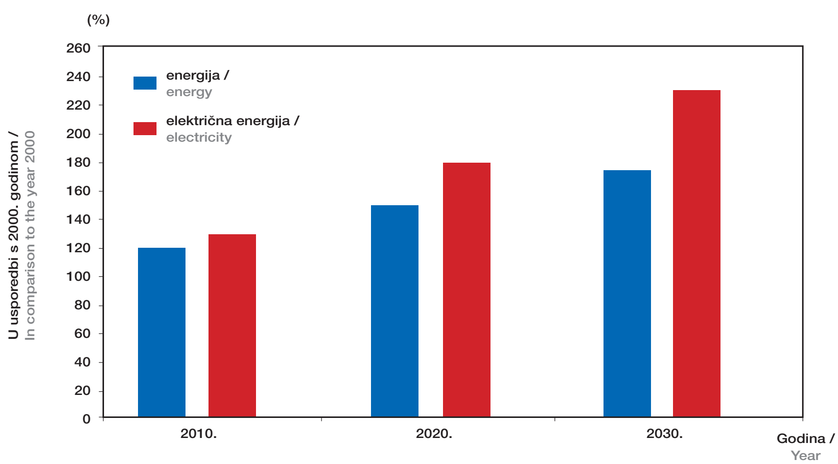
3.1 Potrošnja električne energije u svijetu i Europi
Električna energija, kao oplemenjeni i univerzalno iskoristivi energetski oblik, ima posebnu društvenu važnost. Postoji jaka korelacija između potrošnje električne energije po stanovniku i iznosa bruto društvenog proizvoda po stanovniku. Broj stanovnika u svijetu raste, dok trenutačno četvrtini tog stanovništva električna energija nije dostupna.

To sve mogu biti razlozi ubrzanog rasta potrošnje električne energije u budućnosti u svijetu. Procjene su da će do 2030. godine porasti svjetska potrošnja električne energije od današnjih 16 100 TWh na 31 600 TWh godišnje.

3 ELECTRICAL ENERGY

3.1 Consumption of electrical energy in the world and Europe
Electrical energy, as a refined and universally usable energy form, has particular social importance. There is a strong correlation between the consumption of electrical energy per capita and the gross social product per capita. The number of inhabitants in the world is still growing, while currently one fourth of this population does not have access to electrical energy.

The above could all be reasons for future accelerated growth in the global consumption of electrical energy. Estimates are that by the year 2030 the current world electricity consumption of 16 100 TWh will increase to 31 600 TWh annually.



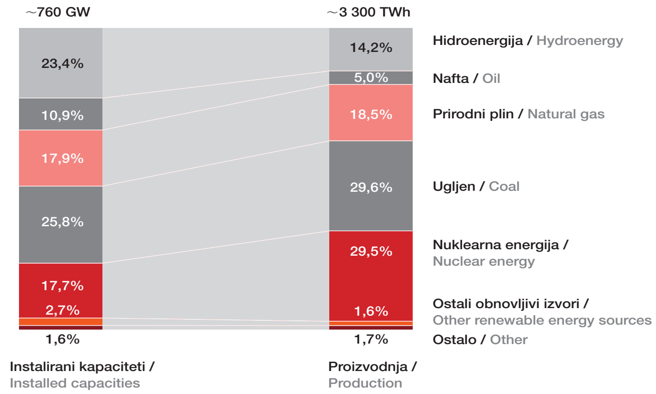
Slika 3
Prognoza globalne potrošnje energije – potrošnja električne energije rasti će brže od potrošnje energije [7]
Figure 3
Forecast global energy consumption – electricity consumption will increase faster than energy consumption [7]

U zemljama EU očekuje se do 2020. godine godišnji rast potrošnje električne energije od 1,6 %/god., što će rezultirati potrošnjom od oko 4 000 TWh, a što predstavlja porast od oko 800 TWh. U 2030. godini očekuje se godišnja potrošnja električne energije od oko 4 300 TWh. Glavni dio te potrošnje pokrivati će elektrane na ugljen (28 %) i kombi elektrane na prirodni plin (28 %). Nuklearna će energija u 2020. godini pokrivati oko 19 % potrošnje, umjesto današnjih 32 %. U pojedinim se scenarijima predviđa porast udjela obnovljivih izvora energije na oko 23 %.

Prema procjenama stručnjaka, fosilna će goriva i nadalje pokrivati najveći dio rasta potrošnje električne energije u svijetu. U 2030. godini će fosilna goriva pokrivati oko 70 % potrošnje električne energije. Obnovljivi izvori energije će igrati značajnu ulogu u svjetskoj primarnoj energetskoj strukturi. U nekim zemljama svijeta porast će uloga i važnost nuklearne energije.

In the countries of the EU, annual growth in electricity consumption of 1,6 % is expected by the year 2020, which will result in consumption of approximately 4 000 TWh, which represents an increase of approximately 800 TWh. In the year 2030, annual electricity consumption of approximately 4 300 TWh is expected. The main part of this consumption will be covered by coal-fired electrical power plants (28 %) and combined natural gas-fired electrical power plants (28 %). Nuclear energy in the year 2020 will cover approximately 19 % of consumption, as opposed to the current 32 %. In individual scenarios, growth in the percentage of renewable energy sources to approximately 23 % is forecast.

According to expert estimates, fossil fuels will continue to cover the greatest percentage of the increased electricity consumption in the world. In the year 2030, fossil fuels will cover approximately 70 % of the consumption of electrical energy. Renewable energy sources will play a significant role in the world primary energy structure. In some countries of the world, the role and importance of nuclear energy will increase.



EU-25 minus Cipar, Estonija, Latvija, Litva, Luksemburg, Malta, Slovenija plus Norveška, Švicarska, Turska / EU-25 minus Cyprus, Estonia, Latvia, Lithuania, Luxembourg, Malta, Slovenia plus Norway, Switzerland and Turkey

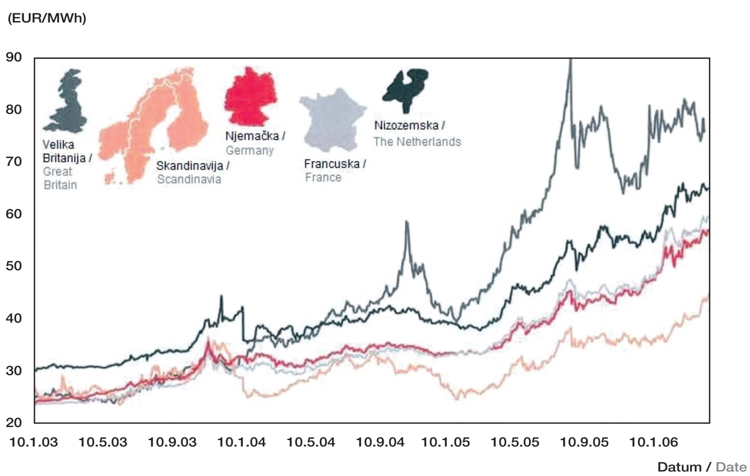
Slika 4
Struktura proizvodnje električne energije u Europi – oko 50 % proizvedene električne energije se bazira na ugljenu i prirodnom plinu
Figure 4
Structure of electricity production in Europe – approximately 50% of the electrical energy produced is based on coal and natural gas.

3.2 Opskrba energijom u Europi u uvjetima globalizacije i liberalizacije tržišta električne energije

Liberalizacija tržišta električne energije u EU početkom devedesetih godina izazvala je sniženje cijene električne energije kao posljedicu smanjenja troškova proizvodnje. Obustavljeni su neracionalni i skupi proizvodni kapaciteti, a zaustavljeno je i investiranje u nove elektrane zbog niske cijene električne energije na tržištu.

3.2 The energy supply in Europe under the conditions of the globalization and liberalization of the electrical energy market

The liberalization of the electrical energy market in the EU at the beginning of the 1990s caused a reduction in electricity prices as a consequence of lower production costs. Irrational and expensive production facilities were shut down and investment in new electrical power plants stopped due to low electricity prices on the market.



Slika 5
Cijene električne energije u trgovini na veliko u Europi – rast cijena električne energije je potaknut rastom cijena fosilnih goriva i CO_2 dozvola
Figure 5
Wholesale electricity prices in Europe – electricity price increases were spurred by higher fossil fuel prices and CO_2 permits

Od 2000. godine evidentan je, međutim, trend porasta cijena električne energije. Od 2002.godine do početka uvođenja trgovine CO_2 certifikatima (početkom 2005.), cijene rastu na razinu ukupnih proizvodnih troškova, koji omogućuju pokretanje novog investicijskog ciklusa u elektroenergetici. Značajni rast cijene od 30 EUR/MWh krajem 1994. godine na 45 EUR/MWh, ostvaren ujesen 2005. godine, uglavnom je utemeljen na cijenama CO_2 certifikata. Prema analizama njemačkog instituta EWI postoji 95 % korelacija između

However, since the year 2000, a trend of increasing electricity prices has been evident. From 2002 to the beginning of the introduction of the trade in CO_2 certificates (early 2005), prices increased at the level of total production costs, which led to the beginning of a new investment cycle in electroenergetics. Significant price increases from 30 EUR/MWh in late 1994 to 45 EUR/MWh in the autumn of 2005 were chiefly due to the prices of CO_2 certificates. According to analyses performed by the Energy Economics Institute (EWI) of the University of Cologne, Germany, there is a rasta cijena električne energije i razine cijena CO_2 certifikata. Tržište CO_2 certifikata je i organizirano da bi utjecalo na cijene električne energije, kako bi se ostvarili željeni ekološki učinci.

95 % correlation between the increase in electricity prices and the price level of CO_2 certificates. The CO_2 certificate market is organized in a manner that affects electricity prices, in order to achieve the desired ecological impacts.

4 TEHNOLOGIJE ČISTOG UGLJENA

Veliki udio ugljika i štetnih balastnih sastojaka čine ugljen najvećim zagađivačem i proizvođačem CO_2 emisija po jedinici proizvedene električne energije. Razvoj tehnologija čistog ugljena je odgovor na rastuću svijest i brigu za zaštitu okoliša. Povijesno su tehnologije čistog ugljena bile usmjerene na smanjenje emisija sumporovih i dušikovih oksida te krutih čestica. Danas, u svjetlu zabrinutosti za klimatske promjene, pažnja se sve više usmjerava prema smanjenju CO_2 emisija. Slijedi pregled tehnologija čistog ugljena.

4.1 Ispiranje ugljena

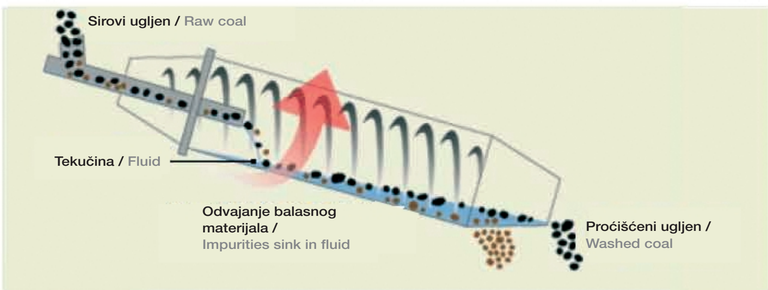
Čišćenje ugljena ispiranjem već je uobičajena praksa u razvijenim zemljama, čime se smanjuju emisije pepela i SO_x, a povoljno djeluje i na proces izgaranja. Ugljen se transportira do termoelektrane zajedno s mineralnim sadržajem koji je nesagorljiv, a može sadržavati i štetne sastojke (poput žive). Jedna od tehnologija odvajanja štetnih sastojaka iz ugljena prikazana je na slici 6.

4 CLEAN COAL TECHNOLOGIES

A large percentage of carbon and detrimental ballast components make coal the greatest pollutant and producer of CO_2 emissions per unit of electricity generated. The development of clean coal technologies is a response to the growing awareness and concern for environmental protection. Historically, clean coal technologies were focused upon reducing emissions of sulfur oxides, nitrogen oxides and solid particles. Today, in the light of concerns regarding climate change, attention is increasingly directed at reducing CO_2 emissions. A review of clean coal technologies follows.

4.1 Washing coal

Cleaning coal by washing is already standard practice in developed countries, which reduces ash and SO_x emissions and also has a favorable effect on the combustion process. Coal is transported to a thermoelectric power plant together with mineral content that is noncombustible and may also contain harmful substances, such as mercury. One of the technologies for removing the impurities from coal is presented in Figure 6.



Slika 6
Ispiranje ugljena [8]
Figure 6
Coal washing [8]

Ugljen se usitnjava i uvodi u spororotirajući bubanj u kojemu se nalazi tekućina veće gustoće, tako da ugljen pluta dok teži, mineralni materijal tone i sa dna se odvodi iz bubnja. Pročišćeni se ugljen zatim melje u finu prašinu pogodnu za izgaranje.

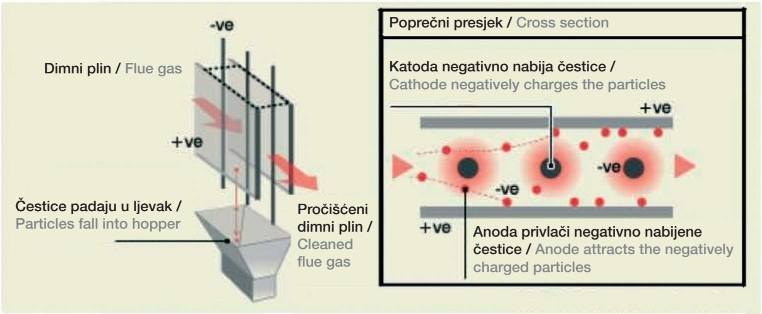
The coal is ground into small pieces and passed through a slowly rotating barrel containing high density fluid, so that the coal floats while the heavier mineral material sinks to the bottom and is removed from the barrel. The washed coal is then ground into a fine powder suitable for burning.

4.2 Odvajanje krutih čestica

Korištenjem elektrostatskih filtara (slika 7) može se iz dimnih plinova odstraniti do 99,7 % pepela. Rade na principu elektrostatskog polja u kojemu se čestice električki nabijaju i sakupljaju na anodi. Osim elektrostatskih filtara koji su u najširoj uporabi, koriste se i vrećasti filtri.

4.2 Removing particulates

By using electrostatic filters, it is possible to remove up to 99,7 % of the ash from flue gasses. This works on the principle of an electrostatic field in which the particles are electrically charged and collected on anodes. In addition to electrostatic filters, which are the most commonly used, bag-like filters are also employed.



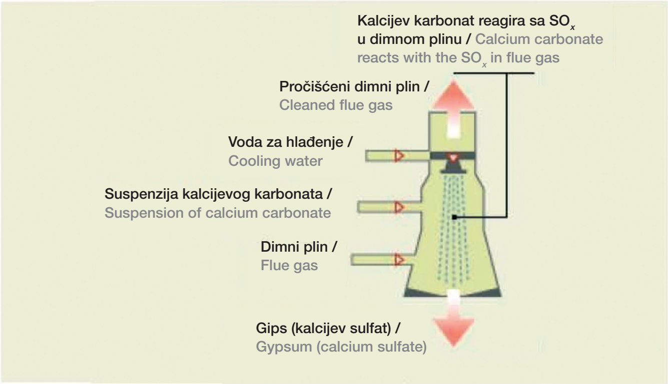
Slika 7
Princip rada elektrostatskog filtra [8]
Figure 7
Operational principle of an electrostatic filter [8]

4.3 Redukcija sumporovih oksida (odsumporavanje)

Sumporovi oksidi (SO_x) nastaju tijekom procesa izgaranja goriva koje sadrži sumpor. Za odstranjivanje sumporovih oksida u konvencionalnim se termo-energetskim postrojenjima najčešće koristi mokri postupak odsumporavanja (slika 8) kojim se iz dimnih plinova odstranjuje do 95 % SO_x. Dimni plinovi reagiraju s raspršenom smjesom kalcijevog karbonata (vapnenac) i vode, pri čemu se stvara gips (kalcijev sulfat) koji se odstranjuje i koristi u građevnoj industriji.

4.3 Reduction of sulfur oxides (desulfurization)

Sulfur oxides (SO_x) occur during the process of the combustion of fuel containing sulfur. In order to remove sulfur oxides in conventional thermal energy plants, the wet scrubbers method of desulfurization is most commonly used, which removes up to 95 % of the SO_x from flue gasses. Flue gasses react with a mixture of calcium carbonate (limestone) and water to form gypsum (a calcium sulfate) that is removed and used in the construction industry.



Slika 8
Odsumporavanje mokrim postupkom [8]
Figure 8
Desulfurization by wet scrubbing [8]

4.4 Redukcija dušikovih oksida (NO_x)

Znatnu redukciju emisije dušikovih oksida može se ostvariti već primarnim mjerama, tijekom izgaranja, što se postiže odgovarajućom konstrukcijom plamenika i stupnjevitim dovođenjem zraka i goriva. Time se smanjuju maksimalne temperature u jezgri plamena i smanjuje se koncentracija kisika u zoni izgaranja. Količinu proizvedenog NO_x na taj se način može smanjiti na vrijednost manju od 300 mg/m^3 (do 40 %).

Sekundarne mjere za smanjenje emisije NO_x, koje se primjenjuju iza zone izgaranja, uključuju selektivnu nekatalitičku redukciju (SNCR) kojom se amonijak uvodi u generator pare na mjestu gdje vladaju temperature dimnih plinova od 850 °C do 900 °C. Time se postiže smanjenje emisije od oko 70 %. Uvođenjem katalizatora ostvaruje se selektivna katalitička redukcija (SCR) kojom se može ostvariti smanjenje emisije NO_x do 90 %. Tim je postupkom do sada stečeno i najveće iskustvo.

4.4 Reduction of nitrogen oxides (NO_x)

Significant reduction in emissions of nitrogen oxides can be achieved using primary methods during combustion, which is achieved through the suitable construction of the burners and the gradual feeding of air and fuel. In this manner, the maximum temperature in the hottest part of the combustion chamber is lowered and the oxygen concentration in the combustion zone is reduced. The amount of NO_x can thereby be reduced to less than 300 mg/m^3 (up to 40 %).

Secondary measures for reducing NO_x emissions, that are applied behind the combustion zone, including selective non-catalytic reduction (SNCR), in which ammonia is injected into the steam generator at the place where the flue gas temperatures are from 850 °C to 900 °C. In this manner, emission reductions of approximately 70 % are achieved. With the introduction of a catalyzer, a selective catalytic reaction (SCR) is achieved, with which it is possible to attain up to 90 % reduction in NO_x emissions. There is the most experience with this procedure.

Tablica 7 – Granične vrijednosti emisija novih postrojenja na ugljen snage >100 MW_t
Table 7 – Limit values for the emissions of new coal-fired plants with power ratings of >100 MW_t

	Granične vrijednosti emisija / Limit values for the emissions (mg/m^3)	
	Europska unija / European Union	Croatia / Croatia
Sumporovi oksidi / Sulfur oxides	200	200
Dušikovi oksidi / Nitrogen oxides	200	200
Čestice / Particles	30	30

Iz tablice 7 vidljivo je da je Hrvatska u potpunosti preuzela europske norme o emisijama štetnih sastojaka iz novih elektrana na ugljen toplinske snage >100 MW_t.

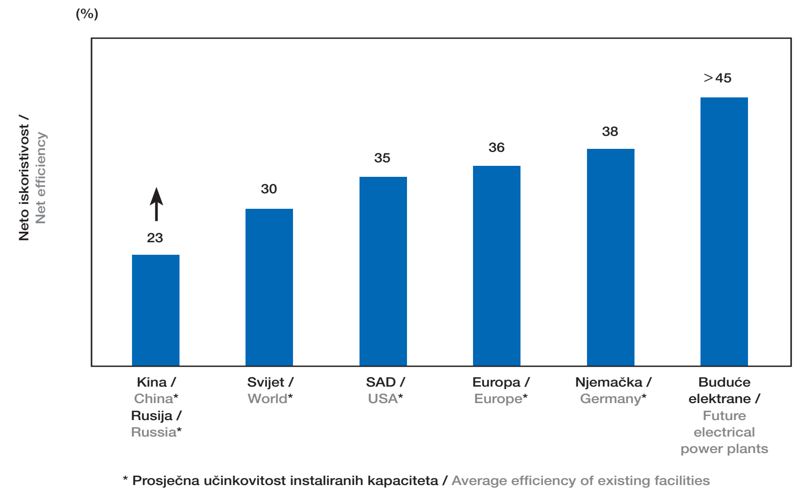
From Table 7, it is evident that Croatia has completely adopted the European norms on hazardous emissions from new coal-fired electrical power plants with power ratings of >100 MW_t.

4.5 Povećanje termičke iskoristivosti postrojenja

Današnje elektrane na ugljen predstavljaju u većini slučajeva konstrukcije stare 20 – 40 godina, s podkritičnim parametrima pare (530 – 540 °C i 140 – 180 bara), sa stupnjem termičke iskoristivosti 36 – 39 %. Neostvareni projekt Lukovo Šugarje predviđao je stupanj iskorisitivosti >43 %, dok zadnje izgrađene njemačke i danske elektrane na kameni ugljen ostvaruju maksimalne stupnjeve iskoristivosti od 47 %. Najnovije konstrukcije elektrana na ugljen s ultra-nadkritičnim parametrima pare (>600 °C i >300 bara) predviđaju stupnjeve iskoristivosti veće od 50 % [9].

4.5 Increasing plant thermal efficiency

In the majority of cases, today's coal-fired electrical power plants are 20 – 40 years old, with subcritical steam parameters (530 – 540 °C and 140 – 180 bars) and thermal efficiency of 36 – 39 %. The unrealized Lukovo Šugarje project was to have had an efficiency of >43 %, while the most recently built German and Danish coal-fired electrical power plants achieve a maximum efficiency of 47 %. The most recently constructed coal-fired electrical power plants with ultra supercritical steam parameters (>600 °C and >300 bars) anticipate efficiency of greater than 50 % [9].



Slika 9
Iskoristivost elektrana na kameni ugljen u svijetu
Figure 9
The efficiency of coal-fired electrical power plants in the world

Elektrane na ugljen i plin s visokim stupnjevima iskoristivosti bit će i nadalje nezaobilazna postrojenja za proizvodnju električne energije [10]. Kad bi se sve postojeće elektrane na ugljen zamijenile suvremenim elektranama visoke iskoristivosti, u svijetu bi se smanjile godišnje emisije CO_2 za 1,9 milijardi tona, što daleko nadmašuje sadašnje potencijale obnovljivih izvora [11].

U tablici 8 prikazana je usporedba pogona TE Plomin 1 i odgovarajuće moderne termoelektrane na ugljen iste snage, koja bi ušla u pogon 2012. godine. Jedina uočljiva razlika je prosječni stupanj iskoristivosti, koji je zbog povećanja parametara pare, porastao s 35 % na 42 %. Posljedica toga je manja količina potrebnog ugljena za istu proizvedenu električnu energiju i posljedično manja godišnja emisija CO_2, (manja za 111 kt_{CO2}/god.). Iskazano kroz financijske pokazatelje, to bi činilo uštedu od 2,2 milijuna EUR/god. uz taksu od 20 EUR/t_{CO2}.

Highly efficient coal-fired and gas-fired electrical power plants will continue to be necessary facilities for the production of electrical energy [10]. If all the existing coal-fired electrical power plants were to be replaced by modern high efficiency electrical power plants, the annual worldwide CO_2 emissions would be reduced by 1,9 billion tons, which greatly surpasses the current potential of renewable energy sources [11].

In Table 8, a comparison is presented of the Plomin 1 Thermoelectric Power Plant and a corresponding modern coal-fired thermoelectric power plant of the same power rating, that would go into operation in the year 2012. The sole noticeable difference is the average efficiency, which due to the increased steam parameter, increased from 35 % to 42 %. The consequence of this is that less coal is needed for the same production of electrical energy and subsequent lower annual emissions of CO_2, (reduced by 111 kt_{CO2}/year). Expressed in financial indices, this would create savings of 2,2 million EUR/year, with a tax of 20 EUR/t_{CO2}.

Tablica 8 – Usporedba TE Plomin 1 s odgovarajućom modernom elektranom
Table 8 – Comparison of the Plomin 1 Thermoelectric Power Plant with a corresponding modern electrical power plant

Parametar / Parameter	Jedinica / Unit	TE / TPP Plomin 1 (1970.)	TE / TPP Plomin 1 (2012.)
Električna snaga / Electrical power rating	MW	100	100
Faktor snage / Power factor	%	70,0	70,0
Faktor CO_2 / Co_2 factor	$kgCO_2/GJ$	94,6	94,6
Prosječni / Mean η	%	35,0	42,0
Električna energija / Electrical energy	MWh	613 200,0	613 200,0
Energija goriva / Fuel energy	MWh	1 752 000,0	1 426 046,5
Donja toplinska vrijednost / Lower thermal value H_d	MJ/kg	25,0	25,0
Potrošnja ugljena / Coal consumption	t/god. / year	252 288,0	205 350,7
Emisija / Emission CO_2	t/god. / year	596 661,1	485 654,4
Cijena električne energije / Electricity price	EUR/MWh	54,42	54,42
CO_2 taksa / CO_2 tax	EUR/tCO_2	20	20

Ako bi se pak dozvolio godišnji rad modernoj elektrani (snage 100 MW) upravo toliki da proizvede jednaku količinu CO_2 kao i stara TE Plomin 1, što zahtijeva nešto veći faktor snage (86 % umjesto 70 %, ali je to povećanje za očekivati zbog boljeg položaja efikasnije elektrane u EES), tada bi se ostvario godišnji porast proizvodnje električne energije za koji bi trebalo 70 vjetroturbina od 1 MW uz očekivani faktor snage od 23 %.

4.6 Dodatno izgaranje biomase

Biomasu čine različiti proizvodi biljnog i životinjskog podrijetla poput granja, piljevine, ostataka žetve ili berbe plodova, životinjski izmet, komunalni i industrijski otpad. Biomasa se smatra neutralnom sa stanovišta proizvodnje CO_2, zbog toga što je nastala uzimanjem CO_2 iz prirode, iako se dio CO_2 proizvodi tijekom kultiviranja, berbe i transporta biomase ili materijala iz kojega je nastala. Istodobno spaljivanje biomase s ugljenom smatra se prijelaznom fazom u procesu supstitucije fosilnih goriva i redukcije CO_2. Dosadašnja iskustva pokazuju da se može spaljivati do 10 % biomase s ugljenom bez nepoželjnih efekata [9]. Istraživanja teže podizanju udjela biomase do 50 %. Korištenje biomase s tehnologijama izdvajanja i skladištenja CO_2 moglo bi osigurati čišćenje atmosfere od emisija CO_2.

4.7 Rasplinjavanje ugljena

Rasplinjavanje ugljena je tehnologija koja po mnogima ima veliku perspektivu da nadomjesti današnje konvencionalne tehnologije spaljivanja ugljena. Obično se koristi u sklopu kombiniranog postrojenja plinske i parne turbine. Ugljen se ne

If we were to permit the annual operation of a modern electrical power plant (with a power rating of 100 MW) to produce the same quantity of CO_2 as the old Plomin 1 Thermoelectric Power Plant, which requires a somewhat larger power factor (86 % instead of 70 %, but this increase is to be expected due to the better position of the more efficient power plant in the EES), an annual increase in electricity production would be achieved that would equal that of 70 wind turbines of 1 MW with an expected power factor of 23 %.

4.6 Additional biomass combustion

Biomass consists of various products of plant and animal origin, such as branches, sawdust, harvest remains, animal excrement, communal wastes and industrial wastes. Biomass is considered neutral from the standpoint of CO_2 production because it originates by taking CO_2 from nature, although some CO_2 is produced during the cultivation, harvest and transport of the biomass or material from which it originates. At the same time, co-firing biomass with coal is considered a transitional phase in the process of the replacement of fossil fuels and the reduction of CO_2. Experience to date shows that it is possible to co-fire up to 10 % biomass with coal with no adverse effects [9]. Research is in progress to raise the level of biomass in co-firing to 50 %. The use of biomass with the technologies of CO_2 capture and storage could be a means of capturing CO_2 emissions from the atmosphere.

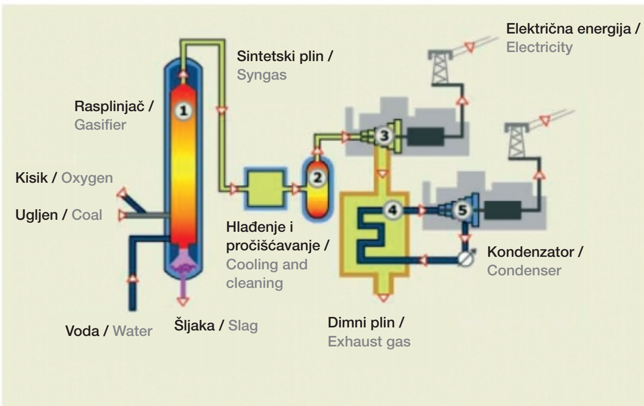
4.7 Coal gasification

Coal gasification is a technology that many feel has great potential for replacing today's conventional coal combustion technologies. It is usually used in spaljuje potpuno, već se rasplinjava uz ograničenu količinu kisika te u reakciji s vodom stvara sintetski plin bogat vodikom.

Postrojenje za rasplinjavanje ugljena (slika 10) primarna je komponenta tehnologije s nultim emisijama. Za sada je tehnologija u fazi razvoja kojim bi se dokazala njena komercijalna isplativost na velikim snagama potrebnim u energetici.

an integrated gasification combined cycle of gas and steam turbines. Coal is not completely burned but is gasified using controlled amounts of oxygen and water, which produces syngas that is rich in hydrogen.

The plant for coal gasification (Figure 10) is the primary component of zero emission technology. For now the technology is in the developmental phase, through which its commercial-scale profitability will be demonstrated for the high power required in energetics.



Slika 10
Integrirano rasplinjavanje s kombiniranim ciklusom (IGCC) [8]
Figure 10
Integrated coal gasification combined cycle plant (IGCC) [8]

Danas postoje samo četiri postrojenja u svijetu koja koriste kombinirani ciklus s integriranim rasplinjavanjem ugljena za proizvodnju električne energije. Njihov je stupanj djelovanja 37 – 45 % [1] i [5]. Neke procjene [9] govore da će buduća postrojenja ostvarivati stupanj iskoristivosti 50 – 60 %.

Today there are only four plants in the world that use the integrated coal gasification combined cycle for the production of electrical energy. Their rates of efficiency are 37–45 % [1] and [5]. Some estimates [9] speak of future plants with efficiencies of 50 – 60 %.

4.8 Izgaranje u fluidiziranom sloju

Kada je brzina upuhivanja zraka za izgaranje dovoljno velika, podižu se čestice krutog goriva sa rešetke te izgaraju u fluidiziranom sloju. Kako bi se osigurala homogena fluidizacija, česticama goriva se obično dodaje kvarcni pijesak finije granulacije. Time se osigurava dobro miješanje goriva i zraka te omogućuje izgaranje kod relativno niskih temperatura od 850 – 900 °C, što stvara male količine termičkog NO_x i smanjuje zašljakivanje. Sustav za kontrolu dodavanja goriva pogodan je za prihvaćanje kalcijevog karbonata (vapnenca), što omogućuje odstranjivanje sumpora iz goriva već u fazi izgaranja. Fluidizirani sloj omogućuje izgaranje svih vrsta krutih goriva, od kvalitetnog ugljena do komunalnog otpada.

4.8 Combustion in a fluidized bed

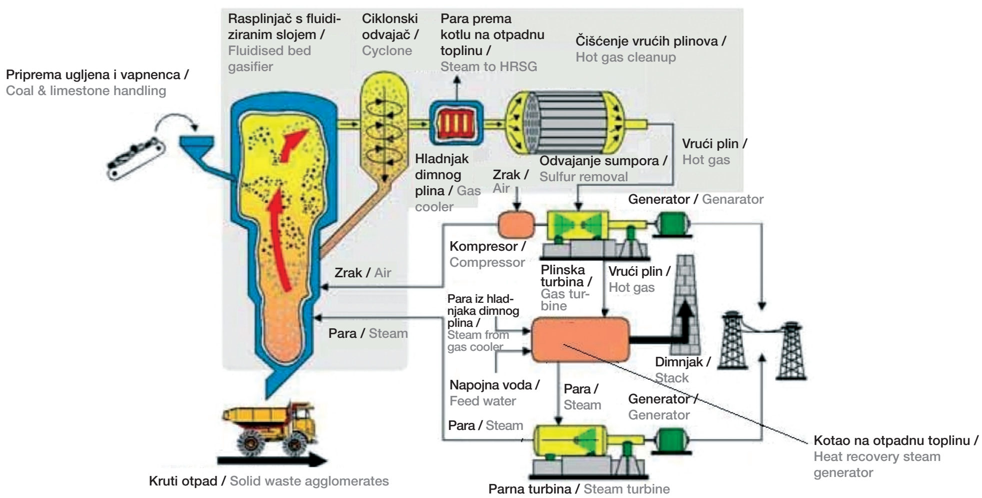
When the velocity of the blown air for combustion is sufficiently high, particles of solid fuel are raised from the grate and burn in the fluidized bed. In order to assure homogenous fluidization, finely granulated quartz sand is usually added to the particulate fuel. This assures that the fuel and air are well mixed and makes combustion at relatively low temperatures of 850 – 900 °C possible, which creates small amounts of thermal NO_x and reduces slag formation. The system for the control of the fuel feed is suitable for receiving calcium carbonate (limestone), which already facilitates the removal of sulfur from the fuel in the combustion phase. The fluidization bed facilitates the combustion of all types of solid fuels, from quality coal to communal wastes.

Tipovi ložišta s fluidiziranim slojem su:

– FBC (*Fluidized Bed Combustion*) – odvija se pri atmosferskom tlaku, a u generatoru pare se stvara para pogodna za pogon parne turbine,
– PFBC (*Pressurized Fluidized Bed Combustion*) – izgaranje se odvija na povišenom tlaku, što poboljšava pogonske karakteristike FBC. U ovu grupu pripada i CFBC (*Circulation Fluidized Bed Combustion*) kod kojega fluidizirani sloj zbog velike brzine upuhivanja zraka cirkulira te se odneseni materijal i gorivo odvajaju iz dimnih plinova i vraćaju u ložište,
– GFBCC (*Gasification Fluidized Bed Combined Cycle*) – temelji se na PFBC kojemu se dodaje rasplinjač u kojemu se stvara sintetski plin. Toplina rasplinjavanja se koristi za proizvodnju pare za parnu turbinu, a sintetski plin izgara u plinskoj turbini. Postrojenje ima vrlo visoki stupanj iskoristivosti (57 – 59 %).

Types of furnaces with a fluidized bed:

– Fluidized Bed Combustion (FBC) – occurs at atmospheric pressure, and steam is formed in the steam generator suitable for driving a steam turbine,
– Pressurized Fluidized Bed Combustion (PFBC) – combustion occurs at elevated pressure, which improves the plant characteristics of FBC. This group also includes Circulation Fluidized Bed Combustion (CFBC), in which the fluidized bed circulates due to the high velocity of the blown air, causing the blown material and fuel to separate from the flue gases and return to the furnace,
– Gasification Fluidized Bed Combined Cycle (GFBCC) – is based upon PFBC, to which a gasifier is added in which syngas is generated. The heat of the gasification is used for producing steam for the steam turbine and the syngas burns in the gas turbine. The plant has a very high level of efficiency (57 – 59 %).



Slika 11 Kombinirano postrojenje s rasplinjavanjem u fluidiziranom sloju GFBCC [12]

Figure 11 Combined plant with a gasification fluidized bed combined cycle, GFBCC [12]

4.9 Izdvajanje CO_2 iz dimnih plinova

Postoje brojne metode za izdvajanje CO_2 iz dimnih plinova, ali još nisu optimirane za primjenu u termoenergetskim postrojenjima na ugljen. Njihov razvoj bio je više usmjeren na dobivanje čistog CO_2 za industrijske potrebe nego li na smanjivanje emisije CO_2 iz energetskih postrojenja.

U bušotinama za zemni plin, gdje je CO_2 pomiješan s metanom, separacija je uspješno provedena. U uporabi je nekoliko procesa, među kojima je proces s vrućim kalijevim karbonatom energetski intenzivan i zahtijeva velika postrojenja, monoetanolaminski proces kojim se dobiva vrlo čisti CO_2, pranje aminom, pranje rashlađenim amonijakom pri čemu se dobivaju kruti karbonati te membranski procesi.

4.9 The capture of CO_2 from flue gases

There are numerous methods for capturing CO_2 from flue gasses but they have still not been optimized for application in thermal coal-fired energy plants. Their development has been more oriented to obtaining pure CO_2 for industrial purposes than for reducing CO_2 from energy plant emissions.

In natural gas wells where CO_2 is mixed with methane, capture is successfully performed. Several processes are in use, including a process with hot potassium carbonate that is energy intensive and requires a large plant, a monoethanolamine process which yields very pure CO_2, amine scrubbing, scrubbing with colled ammonium over getting rigid carbonate and membrane processes.

Izdvajanje CO_2 iz toka dimnih plinova koji nastaju izgaranjem sa zrakom je skupo, budući da je koncentracija CO_2 u zraku najviše do 14 %. CO_2 se tretira kao bilo koji drugi polutant koji se apsorbira iz dimnih plinova prolazom kroz otopinu amina. CO_2 se oslobađa kasnije zagrijavanjem otopine. Ta se metoda također koristi za izlučivanje CO_2 iz prirodnog plina. U procesu se troši energija što podiže troškove postupka.

Postrojenje s integriranim rasplinjavanjem u kombiniranom ciklusu (IGCC) koristi ugljen i vodenu paru da bi proizvelo vodik i ugljikov monoksid (CO) koji se zatim spaljuju u plinskoj turbini kombiniranog postrojenja s parnom turbinom, radi proizvodnje električne energije. Ako se IGCC postrojenje napaja kisikom umjesto zrakom, dimni plinovi sadrže visokokoncentrirani CO_2 koji se lagano može odstraniti postupkom pranja u aminovoj otopini, za otprilike pola cijene u odnosu na postrojenje koje koristi izgaranje sa zrakom. U SAD radi desetak takvih postrojenja. Razvoj IGCC postrojenja koja za izgaranje koriste čisti kisik predviđa uključivanje reaktora za oksidaciju CO s vodom (*shift-reaktor*), tako da će se nastali plin sastojati samo od CO_2 i vodika. Prije izgaranja vodika odvajat će se CO_2 iz smjese tako da će se za proizvodnju električne energije koristiti kao gorivo samo vodik, dok će se komprimirani CO_2 odlagati.

Tehnologija izgaranja s čistim kisikom (*oxy-fuel*) mogla bi se koristiti za obnavljanje postojećih postrojenja na ugljenu prašinu koja su okosnica proizvodnje električne energije u mnogim zemljama, pa time značajno doprinijeti smanjenju ispuštanja CO_2 u atmosferu. Trenutačna je iskoristivost IGCC postrojenja oko 45 %. Odvajanje CO_2 iz procesa rasplinjavanja ugljena u nekim od izvedenih postrojenja već se ostvaruje s niskim pogonskim troškovima. Jedno od njih je Great Plains Synfuels Plant u Sjevernoj Dakoti, gdje se godišnje rasplinjava 6 milijuna tona lignita proizvodeći tako čisti umjetni prirodni plin [1].

4.10 Geološko skladištenje CO_2 (sekvestracija)

Sekvestracija je jedna od tehnologija čistog ugljena koja podrazumijeva odvajanje CO_2 te njegovo skladištenje duboko u zemljinoj unutrašnjosti s ciljem sprječavanja prodora u atmosferu.

The capture of CO_2 from streams of flue gas that occur with combustion in air is expensive, since the concentration of CO_2 in the air is only up to 14 %. CO_2 is treated like any other pollutant that is absorbed from flue gasses by being passed through an amine solution. The CO_2 is later released by heating the solution. This method is also used for removing the CO_2 from natural gas. Energy is expended in this process, which increases the costs of the procedure.

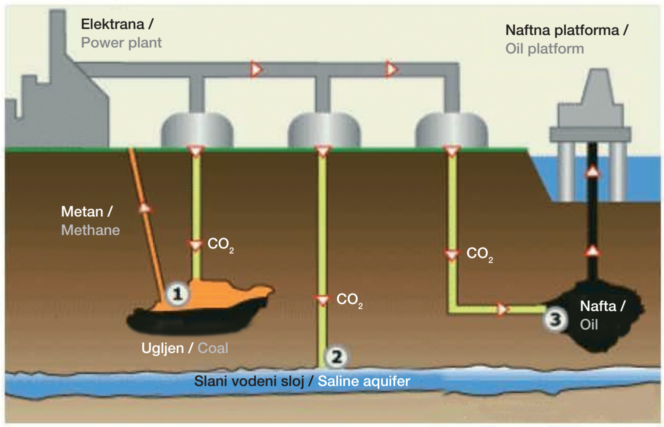
An integrated gasification combined cycle (IGCC) plant uses coal and steam to produce hydrogen and carbon monoxide (CO), which are then burned in a gas turbine in combination with a steam turbine for the production of electrical energy. If the IGCC plant is fed with oxygen rather than air, the flue gases contain highly concentrated CO_2 that can be easily removed by scrubbing in an amine solution, at approximately half the price than in plants that use combustion with air. Approximately ten such plants are in operation in the United States. The development of IGCC plants that use pure oxygen in combustion anticipates the addition of a shift reactor to oxidize the CO with water so that the gas stream will only contain CO_2 and hydrogen. Prior to combustion, the hydrogen is separated from the CO_2 so that only hydrogen is used as the fuel for the production of electricity, while the concentrated pressurized CO_2 is disposed of.

The technology of combustion with pure oxygen (oxy-fuel) could be used for retrofitting existing pulverized coal plants, which are the backbone of electricity generation in many countries, and thereby significantly contribute to reducing the emissions of CO_2 into the atmosphere. Currently, the efficiency of IGCC plants is approximately 45 %. Capturing CO_2 from coal gasification is already performed in some plants at low operational costs. One of them is the Great Plains Synfuels Plant in North Dakota, where 6 million tons of lignite are gasified annually to produce clean synthetic natural gas [1].

4.10 Geological storage of CO_2 (sequestration)

Sequestration is one of the clean coal technologies that involves capturing the CO_2 and storing it deep in the earth, with the goal of preventing it from entering the atmosphere.

Slika 12
Mogućnosti skladištenja CO_2 [8]
Figure 12
Options for CO_2 storage [8]



Na slici 12 prikazane su različite mogućnosti geološkog skladištenja CO_2:

- CO_2 se komprimira u napušteni rudnik ugljena iz kojega potiskuje CH_4 (metan) koji se može koristiti kao gorivo,
- CO_2 se skladišti pod tlakom u geološkom sloju zasićenom slanom vodom,
- CO_2 se komprimira u naftnu bušotinu poboljšavajući iscrpljivanje nafte.

Dosadašnja su istraživanja pokazala da su prikazane tehnologije skladištenja CO_2 tehnički provedive, a sada se ulažu napori da se dokaže njihova komercijalna isplativost za količine koje se proizvode u velikim energetskim i industrijskim postrojenjima.

Izdvojeni CO_2 iz dimnih plinova može se korisno upotrijebiti na komercijalnoj osnovi, za poboljšanje iscrpljivanja nafte. To je primjenjeno u Zapadnom Teksasu te danas preko 3 000 km cjevovoda spaja naftna polja s brojnim izvorima CO_2 u regiji.

Na Great Plains Synfuels Plant u Sjevernoj Dakoti izdvaja se otprilike 13 000 tona CO_2 na dan i od toga 5 000 tona se transportira 320 kilometarskim cjevovodom u Kanadu za poboljšanje iscrpljivanja nafte. U naftnom polju Weyburn na taj se način odlaže oko 85 kubnih metara ugljičnog dioksida po barelu proizvedene nafte, a ukupno će tijekom životnog vijeka od 20 godina biti pohranjeno 19 milijuna tona CO_2.

Ukupno se u SAD godišnje koristi 32 milijuna tona CO_2 za poboljšanje iscrpljivanja nafte, od čega je 10 % iz antropogenih izvora.

Prvi industrijski spremnik CO_2 u svijetu bio je onaj u Norveškom nalazištu plina Sleipner u Sjevernom

Figure 12 presents various options for the geological storage of CO_2:

- CO_2 is pumped into a disused coal field, from which it displaces CH_4 (methane) that can be used as fuel,
- CO_2 can be stored under pressure in a saline aquifer,
- CO_2 is pumped into an oil field, making extraction easier.

Research has shown that the technologies presented for storing CO_2 are technically feasible. Currently efforts are underway to demonstrate their commercial cost effectiveness for the quantities that are produced in large power plants and industrial plants.

Captured CO_2 from flue gases can be useful on a commercial basis, for improving oil extraction. This was demonstrated in West Texas and today over 3 000 km of pipeline connect oil fields with numerous sources of CO_2 in the region.

At the Great Plains Synfuels Plant in North Dakota, approximately 13 000 tons of CO_2 are captured daily, of which 5 000 tons are transported by a 320 kilometer pipeline to Canada for improving oil recovery. At the Weyburn oil field, approximately 85 cubic meters of CO_2 is sequestered per barrel of oil produced and the total during its 20-year lifetime will be 19 million tons of sequestered CO_2.

In the USA, a total of 32 million tons of CO_2 per year are used for enhancing oil recovery, of which 10 % is from anthropogenic sources.

The first industrial CO_2 storage facility in the world was at the Norwegian Sleipner gas field in the North Sea, where 1 million tons annually of compressed liquid CO_2 separated from the methane are injected moru, gdje se 1 milijun t/god. komprimiranog tekućeg CO_2 separiranog iz metana utiskuje u rezervoar na dubini od oko kilometar ispod razine morskog dna i tamo trajno odlaže. Investicija za sekvestracijsko postrojenje od 80 milijuna USD bila je otplaćena u roku od 18 mjeseci, izračunato temeljem neplaćanja takse na ugljik koja je iznosila 50 USD/toni CO_2. Pretpostavlja se da je u tom pješčenjaku (Utsira) moguće pohraniti ukupno 600 milijardi tona CO_2.

U zapadnoj se Australiji predlaže projekt prirodnog plina (Gorgon projekt) koji će od 2009. godine davati prirodni plin s 14 % CO_2. Odvajanje CO_2 i njegova geosekvestracija smanjit će emisije projekta sa 6,7 milijuna na 4 milijuna tona CO_2 godišnje.

Potencijalno korištenje CO_2 u strategiji njegovog odlaganja je i ubacivanje u duboka, teško dostupna ležišta ugljena, odakle istiskuje metan. Trenutačno ekonomska strana napredne ekstrakcije metana iz ugljenokopa nije tako povoljna kao poboljšanje iscrpljivanja nafte, ali je njen potencijal velik.

Potrebe za odlaganjem CO_2 daleko premašuje današnju mogućnost uporabe, ali prikazani primjeri pokazuju praktičnu provedivost tih postupaka. Sigurnost i trajnost odlaganja su ključna pitanja u razmatranju geološkog skladištenja [1].

5 EKONOMSKE I EKOLOŠKE PERSPEKTIVE PROIZVODNJE ELEKTRIČNE ENERGIJE IZ UGLJENA

Na svjetskoj se razini ulažu znatna sredstva i istraživački napori radi povećanja tehnološke izvodljivosti i ekonomske isplativosti korištenja ugljena za proizvodnju električne energije, pri čemu je pažnja najvećim dijelom usmjerena prema smanjenju CO_2 emisija. U sadašnjem je trenutku tehnologija odvajanja i skladištenja CO_2 nastalog izgaranjem fosilnih goriva skupa, s cijenom 40 – 60 USD/t_{CO2} [1]. To daje prirast od oko 3,5 – 5,5 USc/kWh na cijenu električne energije, uz prosječni stupanj iskoristivosti elektrane na ugljen od 35 %.

U Danskoj je u Elsamovoj elektrani snage 420 MW od prošle godine (2006.) započeo europski pilot projekt CASTOR (CO_2 from Capture to Storage), koji ima za cilj odvajanje CO_2 iz dimnih plinova. Prolaskom kroz apsorber, iz dimnih se plinova izdvaja 90 % CO_2 koji se geološki skladišti. Projekt bi trebao pokazati da je moguće smanjiti troškove odvajanja CO_2 sa 50 – 60 EUR/t CO_2 na 20 – 30

into a reservoir at a depth of approximately a kilometer below the sea bed and permanently stored there. The investment in the sequestering plant of USD 80 million was paid back in 18 months, calculated on the basis of the savings on the carbon tax, which amounted to 50 USD/t CO_2. It is assumed that it is possible to store a total of 600 billion tons of CO_2 in this sandstone formation (Utsira).

In West Australia, a project involving natural gas is being proposed (the Gorgon project) that starting in the year 2009 will tap natural gas with 14 % CO_2. The capture of CO_2 and its geosequestration will reduce the emission of the project from 6,7 million to 4 million tons of CO_2 annually.

Another potential use of CO_2 in the strategy of its disposal is injecting it into deep, difficult to access coal seams for the purpose of displacing methane. Currently, the economic side of enhanced coal bed methane extraction from coal beds is not as favorable as enhanced oil recovery but it has great potential.

The need for CO_2 disposal far exceeds today's possibilities for its use but the presented examples demonstrate the practical feasibility of these procedures. The safety and permanence of disposal are key questions in considering geological storage [1].

5 ECONOMIC AND ECOLOGICAL PERSPECTIVES ON THE PRODUCTION OF ELECTRICAL ENERGY FROM COAL

On the world level, considerable funding and research are being invested in order to increase the technological feasibility and cost efficiency of using coal for the production of electrical energy, with the most attention focused upon reducing CO_2 emissions. At the moment, the technology for the capturing and storing of CO_2 that occurs with the combustion of fossil fuels is expensive, costing 40 – 60 USD/t_{CO2}, adding approximately 3,5 – 5,5 USc/kWh to the cost of electricity from a coal-fired power plant with 35 % average efficiency [1]

In Denmark, at the Elsam power plant with a power rating of 420 MW, the European pilot project CO_2 from Capture to Storage (CASTOR) began last year (2006), with the goal of capturing CO_2 from flue gases. By passing the flue gases through an absorber, 90 % of the CO_2 is captured, which is sequestered geologically. The project should demonstrate that it is possible to reduce the costs of capturing CO_2 from 50 – 60 EUR/t_{CO2} to 20 – 30 EUR/t_{CO2}, that geologi-

EUR/t_{CO2}, pokazati da je geološko skladištenje pogodno sa stanovišta kapaciteta, sigurnosti i utjecaja na okoliš te potaknuti razvoj integralne strategije koja će povezati odvajanje, transport i skladištenje CO_2.

U okviru tehnologija čistog ugljena s velikom perspektivom razvoja u posljednje se vrijeme ističe rasplinjavanje (gasifikacija) ugljena s odvajanjem i geološkim skladištenjem CO_2. Mnogi smatraju da se ovom tehnologijom moguće približiti proizvodnji električne energije s nultim emisijama u okoliš. Jedna je studija započeta u 2000. godini u SAD procijenila troškove odvajanja CO_2 u IGCC (*Integrated Gasification Combined Cycle*) postrojenju na 1,7 USc/kWh, uz energetski gubitak od 14,6 %, što odgovara izbjegnutom trošku od 26 USD/t CO_2. Do 2010. treba očekivati da se ti troškovi smanje na 1,0 USc/kWh, uz energetski gubitak od 9 %, što odgovara izbjegnutom trošku od 18 USD/t_{CO2}.

Radna grupa IPCC (*Intergovernmental Panel on Climate Change*) je 2005. godine procijenila troškove odvajanja i skladištenja CO_2 za IGCC postrojenje na 1 – 3,2 USc/kWh, što podiže cijenu električne energije za 21 – 78 %, tj. na 5,5 – 9,1 USc/kWh. Energetski gubitak je procijenjen na 14 – 25 % s odgovarajućim izbjegnutim troškom 14 – 53 USD/t_{CO2}. Ti troškovi uključuju do 5 USD/t za transport i do 8,30 USD/t za geološko skladištenje.

Američki Department of Energy (DOE) postavio je za cilj smanjenje troškova odvajanja i skladištenja CO_2 nastalog izgaranjem fosilnih goriva na vrijednost ispod 3 USD/t_{CO2}, odnosno 0,25 USc/kWh, do 2008. godine, dok nakon 2012. godine ti troškovi ne smiju povećati cijenu električne energije za više od 10 %. DOE odnedavno financira projekt FutureGen vrijedan 1,3 milijarde američkih dolara, čiji je cilj projektirati, izgraditi i voditi pogon postrojenja za proizvodnju električne energije i vodika na bazi ugljena s gotovo nultim emisijama štetnih sastojaka u okoliš. Projekt treba pokazati tehnološku izvodljivost i ekonomsku isplativost takvog postrojenja. Postrojenje će se sastojati od dijela za rasplinjavanje ugljena s dodatnim *water-shift* reaktorom za proizvodnju vodika i ugljikovog dioksida iz vode i ugljikovog monoksida. Oko 90 % CO_2 bit će odvojeno korištenjem membranske tehnologije te geološki skladišteno. Vodik će se koristiti za izgaranje u postrojenju električne snage 275 MW i u gorivnim ćelijama. Izgradnja postrojenja prema projektu FutureGen treba započeti 2009. godine, a postrojenje treba ući u pogon 2012. godine. Očekuje se da će ukupni trošak proizvodnje električne energije za samo 10 % premašiti

cal sequestration is appropriate from the standpoint of capacity, safety and environmental impact, and to stimulate the development of an integrated strategy that will connect the capture, transport and sequestration of CO_2.

Within the framework of clean coal technologies, there has been recent emphasis upon the gasification of coal by the capture and geological sequestration of the CO_2, with the promise of development. Many are of the opinion that with this technology it is possible to achieve coal-based production of electricity with near-zero emission into the environment. A study that began in the year 2000 in the USA put the costs of capturing CO_2 in an integrated gasification combined cycle (IGCC) plant at 1,7 USc/kWh, with an energy loss of 14,6 %, which corresponds to an avoided expenditure of 26 USD/t_{CO2}. By the year 2010, it can be expected that these costs will be reduced to 1,0 USc/kWh, with an energy loss of 9 %, corresponding to an avoided expenditure of 18 USD/t_{CO2}.

In the year 2005, the mitigation working group of the Intergovernmental Panel on Climate Change (IPCC) assessed the costs of the capture and sequestration of CO_2 for an IGCC plant at 1–3,2 USc/kWh, which raises the cost of electricity by 21 – 78 %, i.e. to 5,5 – 9,1 USc/kWh. The energy loss is estimated at 14 – 25 %, with the corresponding avoided expenditure of 14 – 53 USD/ t_{CO2}. These costs include up to 5 USD/t for transport and up to 8,30 USD/t for geological sequestration.

The United States Department of Energy (DOE) set the goal of reducing the CO_2 capture and sequestration costs that arise with the combustion of fossil fuels to a level of below 3 USD /t_{CO2}, i.e. 0,25 USc/kWh by the year 2008, while after the year 2012 these costs should not be permitted to increase the price of electrical energy by more than 10 %. The DOE has recently financed the project FutureGen, valued at USD 1,3 billion, the goal of which is to design, build and operate a plant for the production of electrical energy and hydrogen on the basis of coal, with near-zero emissions of substances that are harmful to the environment. The project should demonstrate the technological feasibility and cost efficiency of such a plant. The plant will consist of a section for coal gasification with an additional water-shift reactor for the production of hydrogen and carbon dioxide from water and carbon monoxide. Approximately 90 % of the CO_2 will be captured by membrane technology and geologically sequestered. Hydrogen will be used for combustion in a plant with a power rating of 257 MW and in fuel cells. According to the FutureGen project, construction of the plant should begin in the year 2009, which should go into operation in the year 2012. It is expected that the total production cost of electricity will only exceed the troškove proizvodnje konvencionalne elektrane sa stupnjem iskoristivosti od 50 %. Također se očekuje da će projekt pokazati mogućnost proizvodnje vodika s troškom od 3,80 USD/GJ, što odgovara cijeni benzina od 12,7 USc/litri [13].

6 TEHNOLOŠKA RAZINA ELEKTRANA NA UGLJEN U SVIJETU I EUROPI

Izgradnja novog proizvodnog parka električne energije u EU-27 predstavlja veliki izazov. Zahtjevi koji se postavljaju na sigurnost opskrbe, štednju resursa i zaštitu klime, uzrokuju visoke investicije u inovativne tehnologije proizvodnje električne energije. U sljedećih 15 – 20 godina zbog starosti elektrana, treba zamijeniti dio postojećeg proizvodnog parka od oko 100 000 MW. K tome treba dodati potrebu za izgradnjom novih elektrana ukupne snage 100 000 MW za pokrivanje rastuće potrošnje električne energije, uglavnom u zemljama koje su pristupile Europskoj uniji [14].

6.1 Njemačka

U Njemačkoj je početkom 2006. godine objavljena namjera izgradnje oko 18 000 MW novih elektrana koje bi trebale ući u pogon do 2011. godine. To je polovina planiranih proizvodnih kapaciteta koji se namjeravaju izgraditi do 2020. godine. Planira se ili je već u izgradnji deset većih elektrana na kameni ugljen jediničnih snaga 600 – 1 500 MW i nekoliko velikih blokova na smeđi ugljen na lokacijama Boxberg i Neurath u koje će se uložiti oko 40 milijardi eura [15].

Steag/EVN grade na lokaciji Duisburg-Walsum elektranu na kameni ugljen bruto snage 750 MW s neto stupnjem iskoristivosti od 45 %, koja bi trebala ući u pogon 2010. godine [16]. Drugi je projekt elektrana na kameni ugljen Herne 5, bruto snage 750 MW, s neto stupnjem iskoristivosti većim od 45 %, čiji se početak izgradnje očekuje u jesen 2007. godine na lokaciji postojeće termoelektrane Herne. Kao gorivo će se koristiti uvozni kameni ugljen, koji će se brodovima dopremati na lokaciju. Novi blok će ući u pogon 2011. godine [16].

Prosječna starost konvencionalnog proizvodnog parka koncerna E.ON iznosi oko 30 godina. Od ukupno 40 000 MW, koliko će 2020. godine biti zamijenjeno u SR Njemačkoj, E.ON će morati zamijeniti najmanje 7 000 MW. Pored izgradnje dva kombi bloka jediničnih snaga 800 MW i 550 MW, namjerava se izgraditi prva u nizu konvoj elektrana na kameni ugljen snage 1 100 MW na

costs of production at conventional power plants by 10 %, with 50 % efficiency. Furthermore, it is expected that the project will demonstrate the possibility of producing hydrogen at a cost of 3,80 USD/GJ, which would be equivalent to gasoline at a cost of 12,7 USc/liter [13].

6 THE TECHNOLOGICAL LEVEL OF COAL-FIRED ELECTRICAL POWER PLANTS IN THE WORLD AND EUROPE

The construction of the new EU-27 electrical generating park represents a great challenge. The requirements regarding the security of supply, savings of resources and climate protection necessitate large investments in innovative technologies for the production of electrical energy. In the next 15 – 20 years, due to the age of the power plants, it will be necessary to replace part of the existing park with a power rating of approximately 100 000 MW. To this it is necessary to add the need for the construction of new power plants with a combined power rating of 100 000 MW for covering growing electricity consumption, mainly in the countries that have acceded to the European Union [14].

6.1 Germany

At the beginning of the year 2006 in Germany, the intention was announced to construct approximately 18 000 MW of new electrical power plants that should go into operation by the year 2011. This is half of the generating capacities planned for construction by the year 2020. Ten large stone coal-fired electrical power plants with unit power ratings of 600 –1 500 MW and several large brown coal-fired blocks at the Boxberg and Neurath locations, in which approximately 40 billion euros will be invested, are planned or under construction [15].

Steag/EVN is building a stone coal-fired electrical power plant at the location of Duisburg-Walsum of a gross power rating of 750 MW with a net efficiency of 45 %, which should go into operation in the year 2010 [16]. A second project is the stone coal-fired electrical power plant Herne 5, with a gross power rating of 750 MW and a net efficiency of greater than 45 %, on which construction is scheduled to begin in the autumn of 2007 at the location of the existing Herne Thermo Electric Power Plant. It will use imported stone coal for fuel, which will be conveyed by ships to the location. The new block will go into operation in the year 2011 [16].

The average age of the conventional production parks of the concern E.ON is approximately 30 years. Of a total of 40 000 MW, which will be replaced in lokaciji Datteln. Ukupna investicija iznosi 1,2 milijarde eura, a tehnički podaci novog bloka dati su tablici 9 [17].

Germany in the year 2020, E.ON must replace at least 7 000 MW. In addition to the construction of two combi-blocks with unit power ratings of 800 MW and 550 MW, there are plans for the construction of the first in a series of stone coal-fired convoy electrical power plants with power ratings of 1 100 MW at the Datteln location. The investment totals 1,2 billion euros and the technical data on the new block are presented in the Table 9 [17].

Tablica 9 – Tehnički podaci novog bloka na lokaciji Datteln
Table 9 – Technical data of the new block at Datteln location

Električna snaga/ Power rating	bruto / gross	1 100	MW
	neto / net	1 055	MW
Daljinsko grijanje / Distance heating		320	MW
Neto stupanj iskoristivosti / Net efficiency		45,2	%
Količina ugljena / Quantity of coal		360	t/h
Proizvodnja (količina) pare / Steam production (quantity)		2 850	t/h
Temperatura pare / Steam temperature		600/620	°C
Tlaki pare / Steam pressure		255/55	bar

Energetska politika koncerna RWE oslanja se na uravnoteženi energetski miks na bazi raznih primarnih resursa i različitih tehnologija proizvodnje električne energije. Na lokaciji Weisweiler dograđene su 2006. godine dvije plinske turbine (2x190 MW) na postojeće blokove na smeđi ugljen jedinične snage 600 MW. Ukupna investicija za tu dogradnju iznosila je 150 milijuna eura. Nakon izgradnje bloka BoA1 na smeđi ugljen na lokaciji Niederaussem, započela je izgradnja dvostrukog bloka na smeđi ugljen, BoA2/3, na lokaciji Neurath, ukupne snage 2 200 MW u kojega će se uložiti 2,2 milijarde eura. Komercijalni pogon bloka očekuje se 2009./2010. godine. Na lokaciji Westfalen planira se izgradnja dvostrukog bloka jedinične snage 800 MW (ukupne neto snage 1 560 MW), u čiju izgradnju će se uložiti 1,5 milijardi eura. Početak komercijalnog pogona očekuje se 2011. godine. Planirana je izgradnja šest takvih dvostrukih blokova [18].

Daljnjem povećanju iskoristivosti elektrana na smeđi ugljen pridonosi postupak predsušenja ugljena, na čijem razvoju RWE radi već 10 godina. Posljednji korak u komercijalizaciji postupka predsušenja smeđeg ugljena je izgradnja prototipnog postrojenja na lokaciji Niederaussem, koje će proizvoditi 110 t/h suhog ugljena za pogon bloka BoA1. Radovi na izgradnji postrojenja započeli su u srpnju 2006. godine, a probni pogon prototipnog bloka se očekuje krajem 2007. godine. Nakon uspješnog pogona novog

The energy policy of the concern RWE relies on a balanced energy mix based upon various primary resources and electricity generation technologies. At the Weisweiler locations, two gas turbines (2x190 MW) were constructed on the existing brown-coal fired blocks with unit power ratings of 600 MW. The total investment for this upgrade amounted to 150 million euros. After the construction of the brown coal-fired BoA1 at the Niederaussem location, construction began of a brown coal-fired double block, BoA2/3, at the Neurath location, with a total power rating of 2 200 MW, in which 2,2 billion euros will be invested. The commercial operation of the block is expected in 2009/2010. At the Westfalen location, construction is planned of a double block with a unit power rating of 800 MW (total net power rating of 1 560 MW), with planned investment in construction of 1,5 billion euros. The beginning of commercial operation is expected in the year 2011. The construction of six such double blocks is planned [18].

Further increase in the efficiency of brown coal-fired power plants will be contributed to by the procedure for predrying coal, which RWE has been developing for 10 years. The final step in the commercialization of the procedure for the predrying of brown coal is the construction of a prototype plant at the Niederaussem location, which will produce 110 t/h of dry coal for the BoA1 block plant. Work on the plant construction began in July 2006 and the trial operation of the block prototype is anticipated in late 2007. After the successful operation of the new postrojenja planira se na bazi stečenih iskustava izgraditi prvu elektranu na suhi smeđi ugljen koja bi trebala ući u pogon oko 2015. godine.

Najvažniji razvojni cilj RWE je elektrana 700 °C, s kojom bi se postigao neto stupanj iskoristivosti od oko 50 %. U okviru projekta COMTES700 (*Component Test Facility for a 700 °C Power Plant*), ispituju se na jednom bloku termoelektrane Scholven materijali za buduću generaciju elektrana s parametrima pare 700 °C [18].

RWE planira 2014. godine pustiti u pogon elektranu na ugljen bez CO_2 emisija, jedinične snage oko 450 MW u koju ulaže oko milijardu eura. Paralelno razvija tehnologije za odvajanje CO_2 u postojećim elektranama na ugljen (postupak pranja CO_2). Također se radi na tehnologiji skladištenja 2,3 milijuna tona CO_2 koja treba biti razvijena do 2014. godine [18].

Tvrtke Kraftwerke Mainz-Wiesbaden AG i Power Generation der Siemens AG su zaključile ugovor o isporuci opreme i izgradnji suvremene elektrane-toplane na kameni ugljen snage 820 MW s električnim stupnjem iskoristivosti od 46 %. Nova će elektrana-toplana emitirati 20 % manje CO_2 u odnosu na klasične elektrane na kameni ugljen te zadovoljavati najstrože zahtjeve zaštite okoliša. Investicijska će ulaganja u novi blok iznositi 940 milijuna eura [19].

Vattenfall raspolaže u Njemačkoj s relativno novim, najsuvremenijim proizvodnim parkom elektrana na smeđi ugljen u svijetu. Za pokrivanje vršnih opterećenja koriste se pumpne hidroelektrane i plinske turbine. Zahvaljujući povoljnim infrastrukturnim uvjetima na lokaciji Boxberg, planira se izgradnja novog bloka na smeđi ugljen snage 675 MW s neto stupnjem iskoristivosti od 43,9 %. Parametri svježe pare su 600 °C i 286 bara s temperaturom međupregrijanja od 610 °C. Komercijalni se pogon očekuje početkom 2011. godine [20].

Vattenfall planira izgradnju novog dvojnog bloka na uvozni kameni ugljen na lokaciji bivše plinske elektrane u luci Hamburg/Moorburg. Primopredaja prvog od dva bloka je planirana za kraj 2011. godine, a drugog bloka do sredine 2012. godine. Blokovi će nakon ulaska u komercijalni pogon opskrbljivati grad Hamburg toplinskom i električnom energijom. Oba bloka raspolagat će pojedinačno električnom snagom od 820 MW i toplinskom snagom od 450 MW. Parametri svježe pare su 600 °C i 276 bara. Blokovi će ostvarivati neto stupanj iskoristivosti od 46,5 % u kondenzacijskom pogonu.

plant, there are plans for the construction of the first brown coal-fired electric power plant, which should go into operation in approximately the year 2015.

The most important developmental goal of RWE is a 700 °C electrical power plant, with which a net efficiency of approximately 50 % would be achieved. Within the framework of the Component Test Facility for a 700 °C Power Plant (COMTES700) project, materials are being tested on one block of the Scholven Thermoelectric Power Plant for the future generation of power plants with steam parameters of 700 °C [18].

In the year 2014, RWE plans to place a coal-fired electrical power plant without CO_2 emissions that would have a unit power rating of approximately 450 MW into operation, in which it is investing approximately a billion euros. It is simultaneously also developing technologies for capturing CO_2 in existing coal-fired electrical power plants (CO_2 scrubbing). It is also working on a technology for the storage of 2,3 million tons of CO_2, which should be developed by the year 2014 [18].

The firms of Kraftwerke Mainz-Wiesbaden AG and Power Generation der Siemens AG have entered a contract on the delivery of equipment and the construction of a modern stone coal-fired electrical power plant/heating plant with a power rating of 820 MW and electrical efficiency of 46 %. The new power plant/heating plant will emit 20 % less CO_2 than classical stone coal-fired power plants and meet the most stringent environmental protection requirements. Investment in the new block will amount to 940 million euros [19].

In Germany, Vattenfall has the relatively new and most modern coal-fired electrical power production park in the world. For covering peak loads, pumped hydroelectric plants and gas turbines are used. Owing to favorable infrastructure conditions at the Boxberg location, the construction of a new brown coal-fired block with a power rating of 675 MW and net efficiency factor of 43,9 % is planned. The parameters of the fresh steam are 600 °C and 286 bars, with a reheat temperature of 610 °C. Commercial operation is anticipated in early 2011 [20].

Vattenfall is planning to construct a new imported stone coal-fired double block at the location of the former gas power plant in the Hamburg/Moorburg Harbor. The transfer of the first of the two blocks is planned for the end of the year 2011 and the transfer of the second by the middle of the year 2012. After entering commercial operation, the blocks will supply the city of Hamburg with heat and electrical energy. Each block will have a electrical energy capacity of 820 MW and a heat energy capacity of 450 MW. The parameters of the fresh steam are 600 °C

U rujnu 2006. godine započelo je projektiranje kogeneracijskog bloka za istodobnu proizvodnju električne energije i topline za grad Berlin, s istim parametrima pare kao kod novih blokova u Hamburgu/Moorburgu. Početak komercijalnog pogona predviđen je za kolovoz 2012. godine [20].

Vattenfall radi na razvoju elektrane na smeđi ugljen bez CO_2 emisije, na bazi *oxy-fuel* tehnologije. Nakon uspješnog pogona test postrojenja predviđa se izgradnja pilot postrojenja koje će se sastojati od postrojenja za razlaganje zraka, parogeneratora snage 30 MW te postrojenja za pročišćavanje dimnih plinova i proizvodnju tekućeg CO_2. Pri nazivnom opterećenju pilot postrojenje će proizvoditi oko 9 t/h tekućeg CO_2, za što je potrebno osigurati 5,2 tone ugljena i 10 t/h kisika. Probni pogon pilot postrojenja je predviđen za treći kvartal 2008. godine [20].

U Njemačkoj je pored navedenog, najavljena izgradnja sljedećih elektrana na kameni ugljen:

- Bremen (swb Erzeugung), blok snage 800 MW, s ulaskom u komercijalni pogon 2011. godine,
- Ruhr (EWMR), blok snage 1100 MW, s ulaskom u komercijalni pogon 2011. godine,
- Baden-Württenberg (Südweststrom), blok snage 750 MW, vrijeme ulaska bloka u pogon je još nepoznato,
- Mainz (Kraftwerke Mainz-Wiesbaden – KMW), blok snage 750 MW, vrijeme ulaska bloka u pogon je još nepoznato [15].

6.2 Poljska, Mađarska i Bugarska

Poljska proizvodi godišnje 100 milijuna tona kamenog i 60 milijuna tona smeđeg ugljena [21]. Instalirana snaga elektrana iznosi 35 406 MW, s bruto proizvodnjom električne energije od 151,8 TWh. Poljska izvozi godišnje oko 15 TWh električne energije [21]. U elektrani Lagisza gradi se prvi i najveći blok na svijetu s nadkritičnim parametrima i kotlom na ugljen s izgaranjem u fluidiziranom sloju (CFB), snage 460 MW, čiji se komercijalni pogon predviđa za 2009. godinu. Krajem 2007. godine tvrtka Elektrownia Patnow pušta u pogon blok nadkritičnih parametara, na smeđi ugljen, snage 460 MW. U elektrani Belchatow se gradi blok s nadkritičnim parametrima, na smeđi ugljen, bruto snage 833 MW i garantiranim stupnjem iskoristivosti od 44,2 % [22].

Na lokaciji Visonta u Mađarskoj, tvrtka Matra Kraftwerk AG, u kojoj je većinski vlasnik njemačko elektroprivredno poduzeće RWE Power, namjerava

and 276 bars. The blocks will achieve a net efficiency factor of 46,5 % in the condenser plant.

The beginning of the design of a cogeneration block for the simultaneous production of electrical energy and heat for the city of Berlin began in September 2006, with the same steam parameters as for the new blocks in Hamburg/Moorburg. The beginning of commercial operation is anticipated in August 2012 [20].

Vattenfall is working on the development of a brown coal-fired electrical power plant without CO_2 emissions, based upon oxy-fuel technology. After the successful operation of the test plant, the construction of a pilot plant is anticipated that will consist of plants for air separation, a 30 MW steam generator, and a plant for scrubbing flue gases and the production of liquid CO_2. At the rated load, the pilot plant will produce approximately 9 t/h of liquid CO_2, for which it is necessary to secure 5,2 tons of coal and 10 t/h of oxygen. The test operation of the pilot plant is planned for the third quarter of the year 2008 [20].

In Germany, in addition to the above, the construction of the following stone coal-fired electrical power plants has been announced:

- Bremen (swb Erzeugung), block with a power rating of 800 MW, scheduled to go into commercial operation in the year 2011,
- Ruhr (EWMR), block with a power rating of 1100 MW, scheduled to go into commercial operation in the year 2011,
- Baden-Württenberg (Südweststrom), block with a power rating of 750 MW, for which the date that it will go into commercial operation is still unknown,
- Mainz (Kraftwerke Mainz-Wiesbaden – KMW), block with a power rating of 750 MW, for which the date that it will go into commercial operation is still unknown [15].

6.2 Poland, Hungary and Bulgaria

Poland produces 100 million tons of stone coal and 60 million tons of brown coal annually [21]. The installed capacity of the power plants amounts to 35 406 MW, with a gross electricity production of 151,8 TWh. Poland exports approximately 15 TWh of electricity each year [21]. In the Lagisza electric power plant, the first and largest block in the world with supercritical parameters and a coal-fired furnace with combustion in the circulating fluidized bed (CFB) and a power rating of 460 MW is expected to go into commercial operation in the year 2009. In late 2007, the company Elektrownia Patnow is putting a brown coal-fired block with supercritical parameters into operation, with a power rating of 460 MW. At the Belchatow electrical power plant, a brown coal-fired block is being constructed with izgraditi novi blok na smeđi ugljen i dograditi plinske turbine na postojeće blokove na ugljen [23].

Od ukupno 9 515 MW instaliranih kapaciteta u Bugarskoj, 47 % električne energije se proizvodi korištenjem domaćeg i uvoznog ugljena. Oko 80 % termoelektrana u Bugarskoj je u pogonu više od 20 godina. Utvrđen je razvoj elektroenergetskog sustava, koji predviđa da će se pored ostalog do 2012. godine izgraditi novih elektrana na ugljen ukupne snage 900 MW [24], koje će biti zamjena za ranije obustavljene nuklearne blokove NE Kozloduy. U razdoblju od 2013. do 2020. godine gradit će se kombi jedinice na prirodni plin i dva nuklearna bloka svaki snage po 1 000 MW.

6.3 Hrvatska, Bosna i Hercegovina, Srbija, Makedonija i Slovenija

Hrvatski sabor je 19. ožujka 2002. godine donio Strategiju energetskog razvoja Republike Hrvatske do 2030. godine, u kojoj su pored ostalog analizirani razni scenariji razvitka proizvodnog parka električne energije Republike Hrvatske i predložena struktura proizvodnih objekata [25].

S obzirom da je razdoblje od otvaranja tržišta električne energije u EU do kraja 2006. godine bilo karakterizirano zastojem izgradnje proizvodnih objekata i da je krajem 2006. godine u Europi pokrenut novi investicijski ciklus izgradnje objekata za proizvodnju električne energije, za očekivati je da će se i u Republici Hrvatskoj uskoro objaviti plan izgradnje objekata proizvodnje električne energije do 2020. (2030.) godine, koji će biti utemeljen na korištenju raznorodnih fosilnih goriva, nuklearne energije i obnovljivih izvora energije.

Obnovljive izvore energije treba poticati i graditi koliko je to objektivno moguće, a elektrane na fosilna goriva i nuklearnu energiju koliko se to mora, da bi se jamčila sigurnost opskrbe potrošača električnom energijom.

U Bosni i Hercegovini vlada je pokrenula investicijski ciklus za izgradnju novih proizvodnih objekata. Pored izgradnje triju novih hidroelektrana u Federaciji BiH gradit će se pet novih blokova na bazi domaćeg ugljena:

– blok 370 MW na smeđi ugljen, na lokaciji TE Tuzla,
– blok 350 MW na smeđi ugljen na području Bugojna,
– blok oko 250 MW na smeđi ugljen na lokaciji TE Kakanj,

supercritical parameters, a gross power rating of 833 MW and a guaranteed efficiency of 44,2 % [22].

At the Visonta location in Hungary, the firm of Matra Kraftwerk AG, in which the majority shareholder is the German company RWE Power, intends to build a new brown coal-fired block and add gas turbines to the existing coal-fired blocks [23].

Of the total 9 515 MW of installed capacities in Bulgaria, 47 % of the electrical energy is produced using domestic and imported coal. Approximately 80 % of the thermal power plants in Bulgaria have been in operation for over 20 years. The development of the electrical energy system has been determined. It is anticipated, among other things, that new coal-fired power plants with a total power rating of 900 MW will be constructed by the year 2012 [24] in order to replace the previously shut down blocks of the Kozloduy Nuclear Power Plant. In the period from 2013 to 2020, combined natural gas-fired units and two nuclear blocks with a power rating of 1 000 MW each will be constructed.

6.3 Croatia, Bosnia and Herzegovina, Serbia, Macedonia and Slovenia

On March 19, 2002, the Croatian Parliament adopted the Energetics Development Strategy of the Republic of Croatia to the Year 2030, in which, among other things, various scenarios are analyzed for the development of the electricity production park of the Republic of Croatia and the structures of the production facilities are proposed [25].

Since the period from the opening of the electricity markets in the EU until the end of the year 2006 was characterized by a standstill in the construction of production facilities and a new investment cycle was initiated at the end of the year 2006 in Europe for the construction of facilities for the production of electrical energy, it can be expected that a plan will soon be announced in the Republic of Croatia for the construction of facilities for the production of electricity by the year 2020 (2030), which will be based upon the use of various types of fossil fuels, nuclear energy and renewable energy sources.

Renewable energy sources should be promoted and constructed to the extent that this is objectively possible, and fossil fuel power plants and nuclear energy to the extent necessary, in order to guarantee a secure supply to the consumers of electrical energy.

In Bosnia and Herzegovina, the government has initiated an investment cycle for the construction of new production facilities. In addition to the construction of three new hydroelectric power plants in the Federation of Bosnia and Herzegovina, five new blocks will be constructed that use domestic coal:

– blok 2x275 MW na smeđi ugljen na lokaciji Kongora.

U Republici Srpskoj planirana je izgradnja sljedećih proizvodnih objekata [26] i [27]:

– novi blok snage 600 MW u TE Gacko na smeđi ugljen,
– nova elektrana snage 430 MW na smeđi ugljen na lokaciji Stanari kod Doboja,
– novi blok u TE Ugljevik.

U Srbiji se planira završetak izgradnje dvaju blokova termoelektrane Kolubara B, bruto snage 2x350 MW. Elektrana se gradi u neposrednoj blizini površinskog kopa smeđeg ugljena Tamnava - Zapadno polje. Izgradnja je obustavljena 1991. godine. TE Kolubara B je ključni proizvodni kapacitet za pokrivanje rasta potrošnje električne energije u Srbiji [28].

Više od 80 % ukupne proizvodnje od 6,6 TWh električne energije u Makedoniji potječe iz elektrana na ugljen (TE Bitola 3x225 MW i TE Oslomej Kičevo 125 MW). Preostala električna energija se proizvodi u hidroelektranama. Pored ostalih elektrana, razvojnim planom je predviđena izgradnja novog bloka na ugljen u TE Bitola snage 225 MW [29].

Proizvodne kapacitete električne energije u Sloveniji čine hidroelektrane, termoelektrane, toplane i NE Krško. Ukupno instalirana snaga (2001.) iznosila je 2 651 MW, od čega 829 MW u hidroelektranama i 1 131 MW u termoelektranama. Godišnja proizvodnja električne energije iznosi oko 10 TWh. U dvije termoelektrane se koristi smeđi ugljen. Najveći dio električne energije iz smeđeg ugljena proizvodi se u termoelektrani Šoštanj, koja je u razdoblju od 1990. do 1999. godine proizvodila 76 % električne energije termoelektrana. Osnovni tehnički i ekonomski podaci novog bloka 600 MW u TE Šoštanj dati su u tablici 10 [30].

– brown coal-fired 370 MW block, at the location of the Tuzla Thermoelectric Power Plant,
– brown coal-fired 350 MW block, in the region of Bugojno,
– brown coal-fired approximately 250 MW block, at the location of the Kakanj Thermoelectric Power Plant,
– brown coal-fired 2x275 MW block, at the Kongora location.

In the Republika Srpska, the construction of the following production facilities is planned [26] and [27]:

– a new brown coal-fired 600 MW block at the Gacko Thermoelectric Power Plant,
– a new brown coal-fired 430 MW power plant at the location of Stanari near Doboj,
– a new block at the Ugljevik Thermoelectric Power Plant.

In Serbia, the completion of two blocks of the Kolubar B Thermoelectric Power Plant is planned, with a gross power rating of 2x350 MW. The power plant is being constructed in the immediate vicinity of the Tamnava - Zapadno polje surface coal mine. Construction was stopped in the year 1991. The Kolubar B Thermoelectric Power Plant is a key production facility for covering increased electricity consumption in Serbia [28].

Over 80 % of the total production of 6,6 TWh of electrical energy in Macedonia originates from coal-fired electrical power plants (the Bitola Thermoelectric Power Plant, 3x225 MW, and Oslomej Kičevo Thermoelectric Power Plant, 125 MW). The remaining electrical energy is produced by hydroelectric power plants. In addition to other electrical power plants, the construction of a new coal-fired block is planned at the Bitola Thermoelectric Power Plant, with a power rating of 225 MW [29].

The electricity production capacities in Slovenia consist of hydroelectric power plants, thermoelectric power plants, heating plants and the Krško Nuclear Power Plant. The total installed capacity in the year 2001 amounted to 2 651 MW, of which 829 MW was in hydroelectric power plants and 1 131 MW in thermoelectric power plants. The annual production of electrical energy amounts to approximately 10 TWh. Brown coal is used in two thermoelectric power plants. The majority of the electrical energy from brown coal is produced at the Šoštanj Thermoelectric Power Plant, which during the period from 1990 to 1999 produced 76 % of the electrical energy of the thermoelectric power plants. The basic technical and economic data of the new 600 MW block at the Šoštanj Thermoelectric Power Plant are presented in the Table 10 [30].

Tablica 10 – Tehnički i ekonomski podaci novog bloka u TE Šoštanj
Table 10 – Technical and economic data of the new block in Šoštanj Thermoelectric Power Plant

Električna snaga / Electrical power rating	600 MW
Stupanj iskoristivosti (neto) / Efficiency (net)	43,12 %
Specifični utrošak topline / Specific heat consumption	8 349 kJ/kWh
Ugljen Velenje / Velenje coal, H_d	10 300 kJ/kg
Emisije / Emissions:	
– SO_2	< 200 mg/Nm^3
– NO_x	< 200 mg/Nm^3
– prašina / particles	< 20 mg/Nm^3
– CO_2 (100 % snage / power)	493 t/h
– buka / noise	< 45 dB(A) na granici TE / at the boundry of the power plant
Investicijska vrijednost / Investment value	637 milijuna eura / million euros
Cijena električne energije / Price of electricity	34,3 EUR/MWh
Cijena ugljena / Price of coal	2,25 EUR/GJ

6.4 Kina i Indija

Jedna trećina očekivanog rasta svjetske potrošnje energije od 1995. do 2020. godine, ostvarit će se u Kini i Indiji, zahvaljujući njihovoj veličini, rastu stanovništva i perspektivama razvoja njihovog gospodarstva [31]. Već danas su te dvije zemlje najveća pojedinačna tržišta opreme za proizvodnju električne energije. Već od 2005. godine u njima se u velikom opsegu grade moderne elektrane na ugljen s parametrima svježe pare od 580 °C i 260 bar. Predviđa se da će se u Kini od 2010. godine graditi elektrane na ugljen s parametrima svježe pare od 610 °C i 300 bara. Za najveći dio planirane nove izgradnje elektrana na ugljen oprema će se proizvoditi u Kini i Indiji.

U Indiji se potrošnja električne energije znatno povećala u posljednjih 5 – 10 godina. Sve veći zahtjevi i potrebe za električnom energijom nisu bile istodobno popraćene izgradnjom novih proizvodnih jedinica, zbog čega se pojavljuju problemi u opskrbi električnom energijom. Za pokrivanje rastuće potrošnje električne energije potrebno je u idućih 5 – 6 godina izgraditi novi proizvodni park snage 68 000 MW [32]. Tako se očekuje da će do 2012. godine u Indiji biti instalirano 205 000 MW proizvodnih kapaciteta. Primjer izgradnje novih kapaciteta na ugljen predstavljaju jedinice 3x660 MW termoelektrane Sipat s nadkritičnim parametrima, koje gradi National Thermal Power Corporation. Probni pogon se očekuje početkom 2009. godine. Zatim to su šest ultra-mega projekata koje gradi indijska vlada, svaki kapaciteta 4 000 MW s pet jedinica po 800 MW (ukupno 24 000 MW) na bazi tehnologije s nadkritičnim parametrima

6.4 China and India

One third of the expected growth in world energy consumption from 1995 to 2020 will occur in China and India, owing to their size, population growth and the prospects for the development of their economies [31]. Already today, these two countries are the largest individual markets for equipment used in the production of electrical energy. Since the year 2005, various types of modern coal-fired electrical power plants have been under construction, with fresh steam parameters of 580 °C and 260 bars. It is expected that starting in the year 2010, China will be building coal-fired electrical power plants with fresh steam parameters of 610 °C and 300 bars. For the majority of the planned new construction of coal-fired electrical power plants, the equipment will be manufactured in China and India.

In India, the consumption of electrical energy has significantly increased during the past 5 –10 years. The ever increasing requirements and demands for electrical energy were not simultaneously accompanied by the construction of new production units, due to which problems occur in the electricity supply. For covering the growing consumption of electrical energy, it will be necessary to build a new production park with a power rating of 68 000 MW in the next 5 – 6 years [32]. Thus, it is expected that by the year 2012, 205 000 MW of production capacities will be installed in India. Example of the construction of new coal-fired capacities include the 3x660 MW units of the Sipat Thermoelectric Power Plant with supercritical parameters being constructed by the National Thermal Power Corporation. Test operation is anticipated in early svježe pare [32]. Svaki ultra-mega projekt stoji 4,3 milijarde američkih dolara. U tijeku su pripreme na izgradnji prvog projekta na lokaciji North Karanpura [22].

U Kini se 80 % proizvodnje električne energije ostvaruje na bazi ugljena. Nagli razvoj kineskog gospodarstva prati povećanje potrošnje električne energije, što je rezultiralo enormnim rastom proizvodnih kapaciteta. U 2003. godini je naručeno preko 100 000 MW elektrana na bazi ugljena. Neki primjeri izgradnje elektrana na ugljen obuhvaćaju:

- termoelektrana Changshu (3x600 MW) na bitumenizirani ugljen je prva jedinica nove generacije elektrana s nadkritičnim parametrima u Kini. Prvi blok je u trajnom pogonu i ostvaruje pogonsku snagu od 670 MW,
- termoelektrana Wai Gao Qiao II, s 2x900 MW s nadkritičnim parametrima pare (542 °C, 279 bara) i neto stupnjem iskoristivosti većim od 42 %,
- treća faza termoelektrane Wai Gao Qiao 2x1 000 MW (u izgradnji) s parametrima pare od 605 °C i 275 bara [33],
- termoelektrana Huaneng Yuhuan je prva kineska proizvodna jedinica s ultra-nadkritičnim parametrima. Izgradit će se četiri jedinice, prve dvije ulaze u pogon 2007., a druge dvije 2008. godine [12],
- treći blok termoelektrane na ugljen Waigaoqiao III s ultra-nadkritičnim parametrima i snagom 2x1 000 MW (u izgradnji).

6.5 Australija, Kanada i SAD

Ove godine ulazi u pogon termoelektrana na ugljen Kogan Creek u Queenslandu, Australija, snage 750 MW, s nadkritičnim parametrima. To će biti blok s najvećom jediničnom snagom u Australiji.

Od 2005. godine u Kanadi je u pogonu termoelektrana Genesee III, kao prva elektrana na ugljen u Sjevernoj Americi s nadkritičnim parametrima, snage 500 MW i s neto stupnjem iskoristivosti od 42 %. Bow City Project-Luscar predviđa u južnoj Alberti izgradnju dviju jedinica na ugljen od 1 000 MW s nadkritičnim parametrima. Očekuje se početak izgradnje u 2007. godini, prva faza bit će u pogonu 2010. godine, a druga 2014. godine.

U SAD se nalazi u fazi izgradnje više objekata od kojih će se spomenuti:

- izgradnja treće jedinice u termoelektrani Comanche Station u Coloradu snage 750 MW s nadkritičnim parametrima. Komercijalni pogon te jedinice se očekuje 2008. godine,

2009. There will also be six ultra-mega projects built by the Indian government, each with a capacity of 4 000 MW with five 800 MW units (a total of 24 000 MW), based on technology with supercritical fresh steam parameters [32]. Each of the ultra-mega projects costs USD 4,3 billion. Preparations are underway for the construction of the first project in the North Karanpura location [22].

In China, 80 % of energy production is based on coal. The rapid development of the Chinese economy is accompanied by increased electricity consumption, which has resulted in enormous growth in the production capacities. In the year 2003, coal-fired power plants with over 100 000 MW of rated power were ordered. Some examples of the construction of coal-fired electrical power plants are as follows:

- the Changshu Thermoelectric Power Plant (3x600 MW), fired by bituminous coal, the first unit of the new generation of electrical power plants with supercritical parameters in China. The first block is in permanent operation and has achieved a power rating of 670 MW,
- the Wai Gao Qiao II Thermoelectric Power Plant, with 2x900 MW and supercritical steam parameters (542 °C, 279 bars) and a net efficiency of greater than 42 %,
- the third phase of the Wai Gao Qiao Thermoelectric Power Plant, 2x1 000 MW (under construction), with steam parameters of 605 °C and 275 bars [33],
- the Huaneng Yuhuan Thermoelectric Power Plant, the first Chinese production unit with ultra-supercritical parameters. Four units will be constructed. The first two will go into operation in 2007 and the second two in the year 2008 [12],
- the third block of the coal-fired Waigaoqiao III Thermoelectric Power Plant, with ultra-supercritical parameters and a power rating of 2x1 000 MW (under construction).

6.5 Australia, Canada and the USA

This year, the coal-fired power plant at Kogan Creek in Queensland, Australia, with a power rating of 750 MW and supercritical parameters, will go into operation. It will be the block with the highest unit power rating in Australia.

Since the year 2005, the first coal-fired power plant in North America with supercritical parameters has been in operation at the Genesee III Thermoelectric Power Plant in Canada, with a power rating of 500 MW and a net efficiency of 42 %. The Bow City Project-Luscar in southern Alberta anticipates the construction of two coal-fired units with a power

– Mid American Power u Iowa – 790 MW,
– WE Energy u istočnom Wisconsinu – 2x650 MW,
– TXU u Teksasu – 2x860 MW, termoelektrana Oak Grove 1 i 2 na smeđi ugljen,
– Peabody u Illinoisu – 2x750 MW, ulaze u pogon 2010. godine,
– termoelektrana DTE u Kansasu – 600 MW,
– termoelektrana LG&E u Kentuckyju – 732 MW,
– termoelektrana WPSC u Wisconsinu – 520 MW,
– TXU je objavila plan izgradnje 11 novih jedinica s nadkritičnim parametrima na 9 postojećih lokacija, čije bi prve jedinice mogle ući u pogon već 2010. godine [22].

rating of 1 000 MW and supercritical parameters. Construction is expected to begin in the year 2007. The first phase will be in operation in the year 2010 and the second in the year 2014.

In the USA, several facilities are in the construction phase, of which the following will be mentioned:

– the construction of the third unit in the Comanche Station Thermoelectric Power Plant in Colorado, with a power rating of 750 MW and supercritical parameters. The commercial operation of this unit is expected in 2008,
– Mid American Power in Iowa – 790 MW,
– WE Energy in eastern Wisconsin – 2x650 MW,
– TXU in Texas – 2x860 MW, the brown coal-fired Oak Grove Thermoelectric Power Plants 1 and 2,
– Peabody in Illinois – 2x750 MW, going into operation in the year 2010,
– the DTE Thermoelectric Power Plant in Kansas – 600 MW,
– the LG&E Thermoelectric Power Plant in Kentucky – 732 MW,
– the WPSC Thermoelectric Power Plant in Wisconsin – 520 MW,
– TXU has announced the planned construction of 11 new units with supercritical parameters at 9 existing locations, the first of which could go into operation in the year 2010 [22].

7 ZAKLJUČAK

Usprkos svim problemima koji prate uporabu ugljena u proizvodnji električne energije, njegovo korištenje u zadovoljavanju svjetskih potreba za električnom energijom bit će i idućih desetljeća neizbježno. Pod pritiskom neodgodivog investiranja u nove proizvodne kapacitete, ali i svijesti o ekološkim i klimatološkim posljedicama korištenja fosilnih goriva, u svijetu se ulažu golema sredstva u unaprjeđenje tehnologije korištenja ugljena. Neka dostignuća tog razvoja, poput visoke termičke efikasnosti procesa i ostvarive niske razine zagađenja okoliša, sastavni su dio komercijalne ponude energetske opreme na svjetskom tržištu. Tehnologije proizvodnje električne energije iz fosilnih goriva s nultom emisijom CO_2 u atmosferu još nisu razvijene do razine komercijalne isplativosti, ali realno je očekivati da će se i to ostvariti idućih desetljeća. Dostignuća u razvoju tehnologija čistog ugljena treba uzimati u obzir pri strateškom planiranju izgradnje proizvodnih kapaciteta u hrvatskom elektroenergetskom sustavu, jer se jedino oslanjanjem na raznorodne primarne energente, pa jednim dijelom i na ugljen, može dugoročno osigurati pouzdanost opskrbe električnom energijom.

7 CONCLUSION

Despite all the problems that accompany the use of coal in the production of electrical energy, its use in meeting world electricity demand will be unavoidable in the coming decades. Under the pressure of inevitable investment in new production capacities, but also awareness of the ecological and climatic consequences of the use of fossil fuels, enormous funding is being invested around the world in improving the technology for the use of coal. Some of the achievements of this development, such as the high thermal efficiency of the process and the achievement of a low level of environmental pollution, are integral parts of the commercial offer of energy equipment on the world market. The technologies for the production of electrical energy from fossil fuels with zero emission of CO_2 into the atmosphere have still not been developed to the level of commercial cost effectiveness but it is realistic to anticipate their development within the coming decades. The achievement in the development of clean coal technology should be taken into account in the strategic planning of the construction of production capacities in the electrical energy system of the Republic of Croatia because only through reliance upon a variety of primary power sources, including coal, will it be possible to assure the long-term reliability of the electricity supply.

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