NU ENERGY™: COKE MAKING TECHNOLOGY FOR CURRENT CHALLENGES

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Abstract

This paper deals with a technology for formed coke production. Milestones in the development of this technology are summarized. Then, the equipment and the process are described. The environmental impact is briefly addressed. The products obtained along the processes, including char, gas, liquids and coke are characterized, and possible applications are mentioned. As an example, an economical evaluation of a given project is detailed. Finally, a coke cost exercise is carried out.

1. Introduction

The development of **NUENERGY™** started in 1988. Milestones were as follows:

- 1988-1990: First equipment and batch process testing [1, 2].
- 1991-2000 10 t per day pilot plant in Bristol, Virginia, USA [3, 4, 6].
- 2000-2005 Progress in research and development in pilot plant [6].
- 2006-2009 Pilot plant in Conway, Arkansas, USA [5, 6]; briquetting and char calcining for formed coke at General Shale Brick Plant, Virginia USA [6]. 52 coals tested.
- 2009-2011 Project of first commercial demo scale plant [5, 7].
- 2010 License to ArcelorMittal to test **NUENERGY™** technology [6].
- 2012 Pyrolyzer Furnace Apparatus and Method for Operations patented [8].
- 2013 Method of Making Char patented [8]; started permits to build a 50.000 tpa plant [8]

In the following, process steps and equipment are analyzed, as well as the environmental footprint. Products obtained / recovered and their respective industrial applications are discussed. Finally, operating costs and financial indicators are estimated.

2. Process steps and equipment

NU ENERGY™ includes two processes, one to produce char (**NUCARBON**™), liquids (**NULITE**™) and gas and the other for formed coke (**NUCOKE**™).

Process 1. Figures 1 to 3 present schemes of coal stocking and preparation, char production equipment and gas treatment.

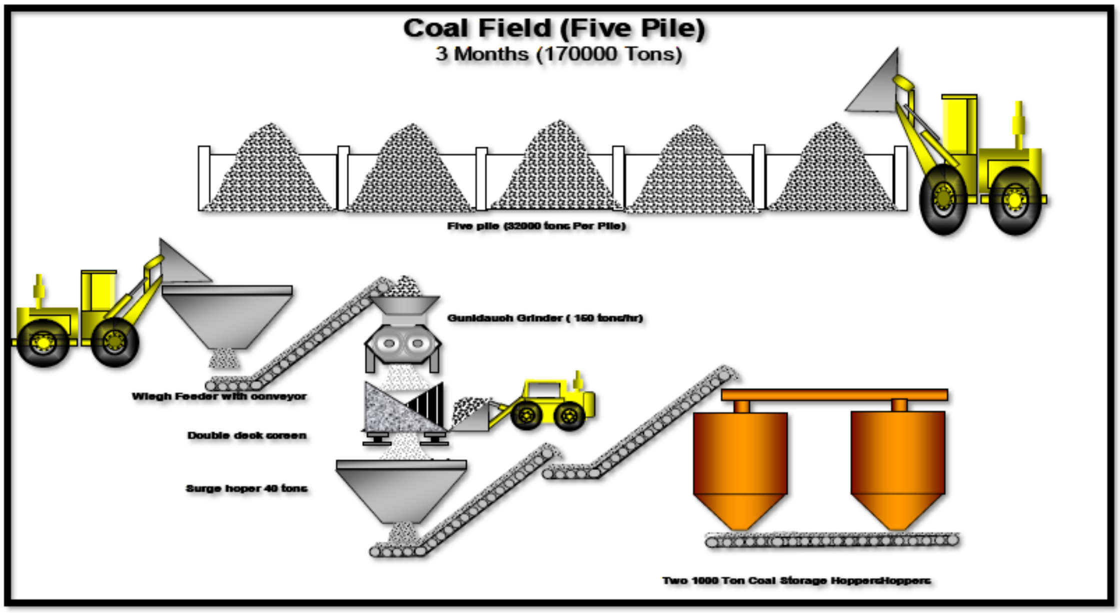

Figure 1. Coal Storage and Grinding.

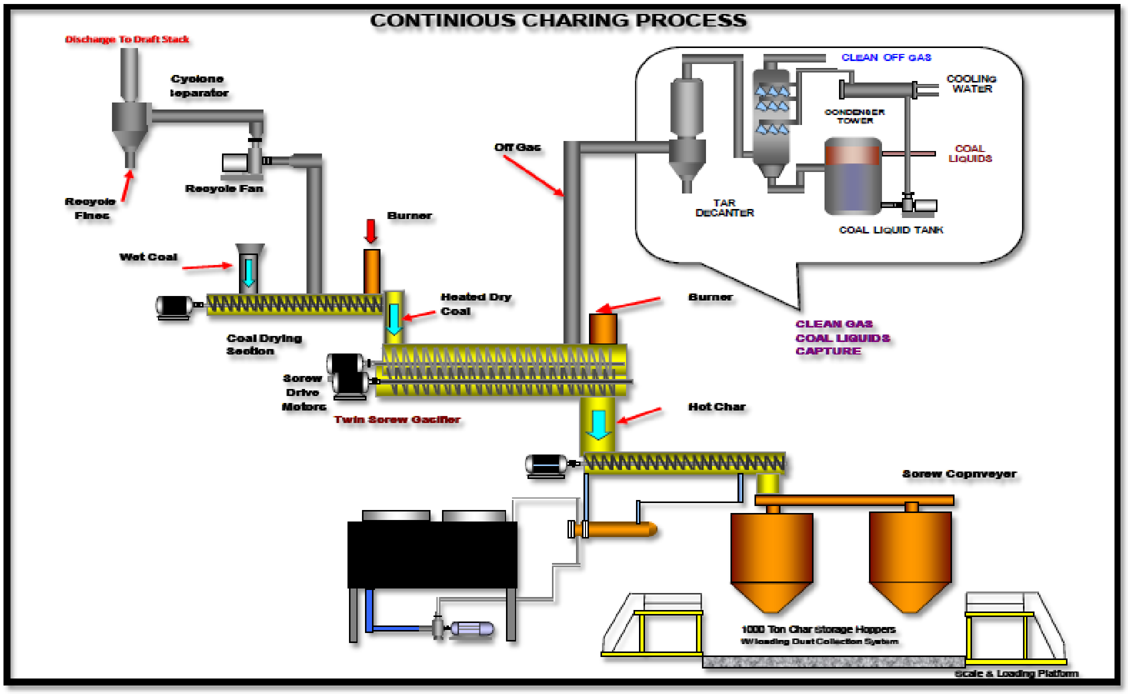

Figure 2. Coal Drying, Pyrolysis, and Off Gas Condensation & Char cooling.

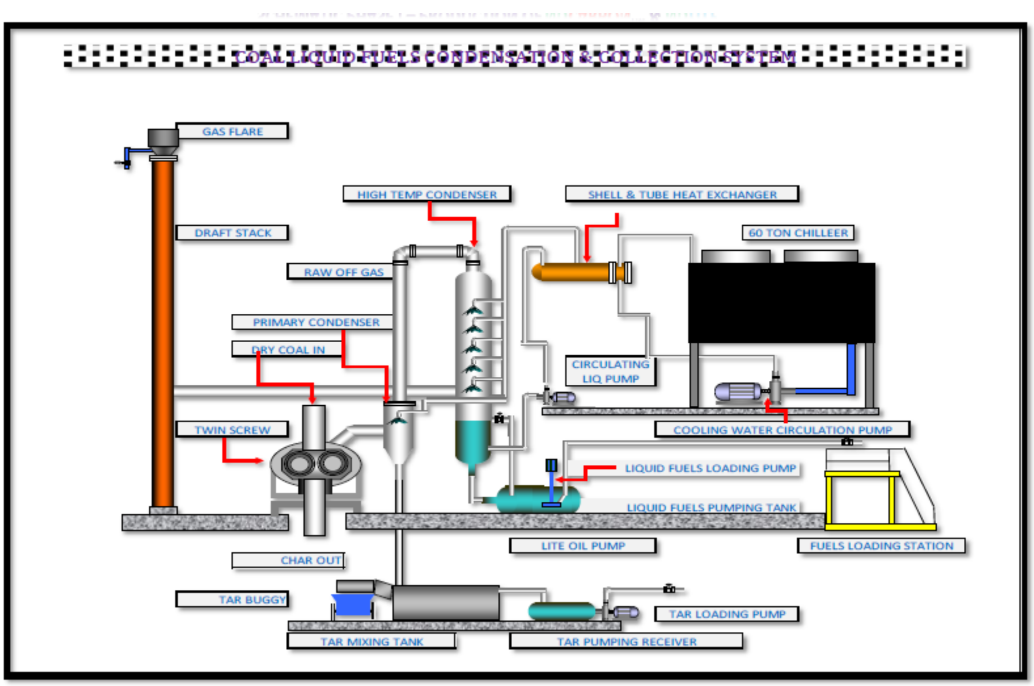

Figure 3. Treatment of raw gas.

The process includes the followings steps [6]:

- Stocking and milling of coal
- Coal drying, by means of an endless screw, with heat being produced by a combustor burning part of the clean gas produced in the process

- Coal pyrolysis in twin screws, heating coal to 427 ºC – 650 ºC, in absence of air, for 20 minutes, with low heating rate, to preserve the quality of condensed liquids. As a consequence of thermal decomposition of coal, volatile matter is released. Required heat is obtained by burning part of the clean gas produces. Char yield is estimated as follows:

  $\eta_{char} = 100 - VM_{coal} + VM_{char} - H_20_{coal}$, in %

- Char cooling to below 260º C, in an endless screw, with water

- Char grinding

- Treatment of raw gas produced, by means of a primary condenser to recover tar and a tower to recover light oil containing BTX. 55% of released volatile matter corresponds to recovered liquids and 45 % to clean gas. The yield of recovered liquids and clean gas is obtained as follows:

  $\eta_{liquids} = 0.55 \times (VM_{coal} - VM_{char})$, in %

  $\eta_{clean\ gas} = 0.45 \times (VM_{coal} - VM_{char})$, in %

  Around 40% of clean gas is recycled to cover the thermal needs of the process. The other 60% should be commercialized.

In table 1, properties and yields of selected coals are presented [3, 4]. Bituminous low-volatile coals have a higher char yield, but they are expensive and scarce. Thermal coal have lower yield but are cheaper and more available. Sub-bituminous coals are cheap, too, but present much lower yield.

Coal Name	Pocahontas 3		Teco Myra		PRB	
Coal type	Bituminous, low volatile		Thermal coal		Sub-Bituminous	
Properties	Coal	Char	Coal	Char	Coal	Char
Moisture (%)	6.40	0.27	3.0	1.3	27.1	0.1
Volatile matter, dry base (%)	17.39	5.36	35.2	8.4	45.8	7.7
Fixed carbon, dry base (%)	74.92	86.11	56.1	82.0	44.7	77.4
Ash, dry base (%)	7.69	8.53	8.7	9.6	9.5	14.9
Sulfur (%)	0.69	0.66	0.88	0.79	0.35	0.57
Heat Value, dry base (Btu/lb.)	14,452	13,967		14,354	11,449	12,508
η_{char} (%)	100	81.6	100	70.2	100	34.8
$\eta_{liquids}$ (%)		N/D	100	14.7		N/D
$\eta_{clean\ gas}$ (%)		N/D	100	12.1		N/D
Water vapor (%)		N/D	100	3.0		N/D
Total (%)			100	100		

Table 1. Properties and yield of selected coals and char [3, 4].

To estimate the yield of clean gas generated, gas used in the process and gas available for sale, the Teco Myra coal test data are used, see table 2.

$\eta_{clean\ gas}$ (%)			12.06
$\eta_{clean\ gas}$ (lb./t coal))			241
Gas component	%	LHV (Btu/lb.)	Q (Btu/t coal)

Methane	80.57	21,433	4,161,823
Ethane	8.66	20,295	423,720
Propane	2.51	19,834	120,112
I-Butane	0.05	19,976	2,292
N-Butane	0.59	19,976	28,250
I-Pentane	0.72	19,322	33,751
N-Pentane	0.45	19,322	20,815
Hexane	1.41	18,976	64,496
Oxygen	0.01		
Carbon dioxide	4.92		
Nitrogen	0.10		
Total	100	159,134	4,855,259
Q (mm Btu/t coal)			≈ 5
Q process (mm Btu/t coal)			≈ 2
Q available (mm Btu/t coal)			≈ 3

Table 2. Composition of gas and heat generated by pyrolysis of Teco Myra coal.

In figure 4, a flow diagram, including material and energy balance is presented, for the case of Teco Myra coal.

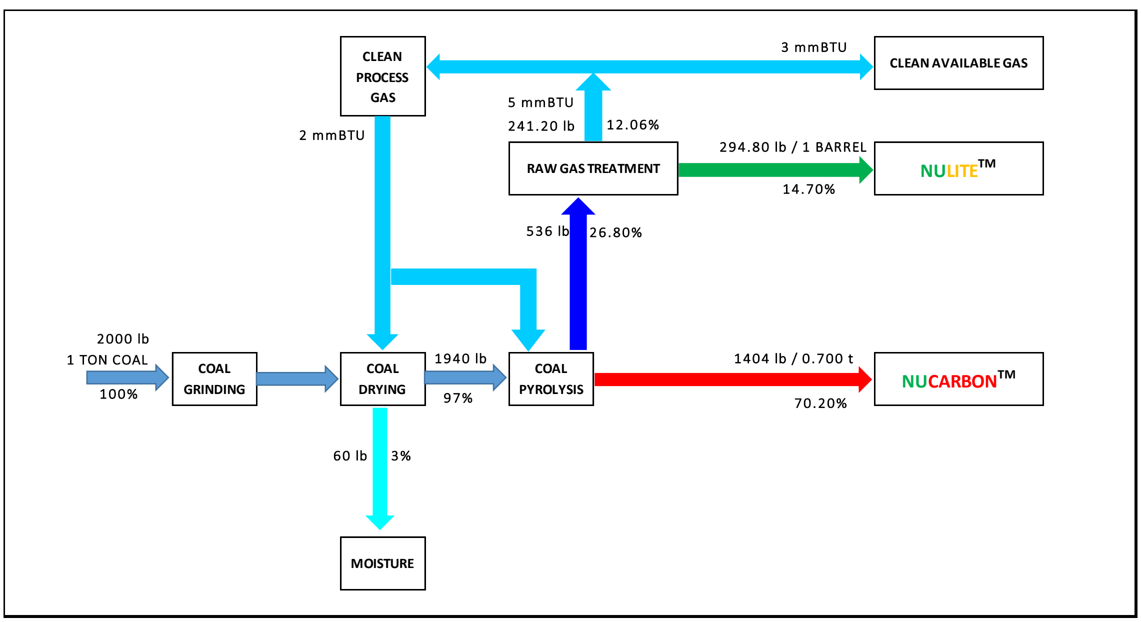

Figure 4. Flow diagram with energy and material balance for Teco Myra coal.

Process 2. In this process, formed coke **NUCOKE**™ is produced. The steps for the process are as follows [3]:

- Silos for **NUCARBON**™, fines, coking coal and binder.
- Dosing and mixing. For good quality coke, a typical mix is 60% **NUCARBON**™, 30% coking coal and 10% tar pitch.

- Briquetting of the mix
- Coking. This is carried out in a continuous tunnel oven, with several heating zones, were the Green briquettes, charged in ceramic wagons, are calcined to around 1100 ºC. The formed coke exits the tunnel furnace and enters the quenching tower. The gas produced in the process can be reused as a source of process heat.

A simplified scheme of the process is shown in figure 5 and a block diagram in figure 6.

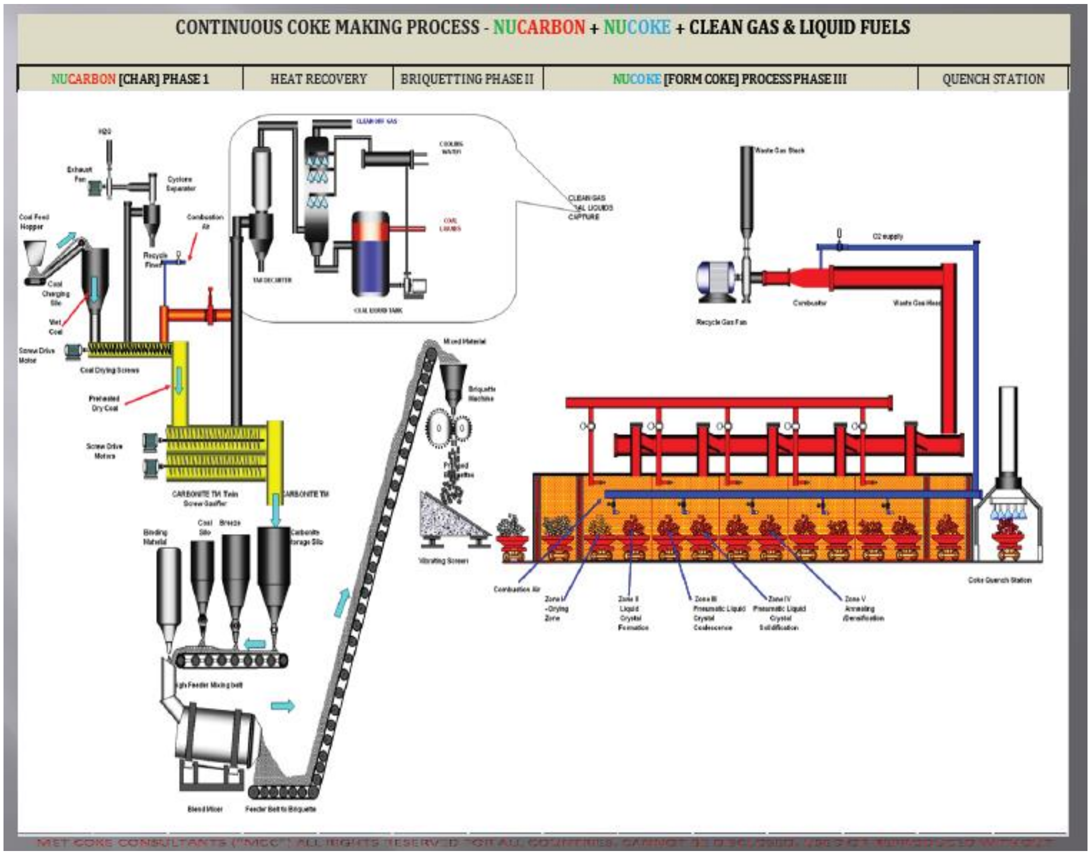

Figure 5. Simplified scheme of process for formed coke **NUCOKE**™.

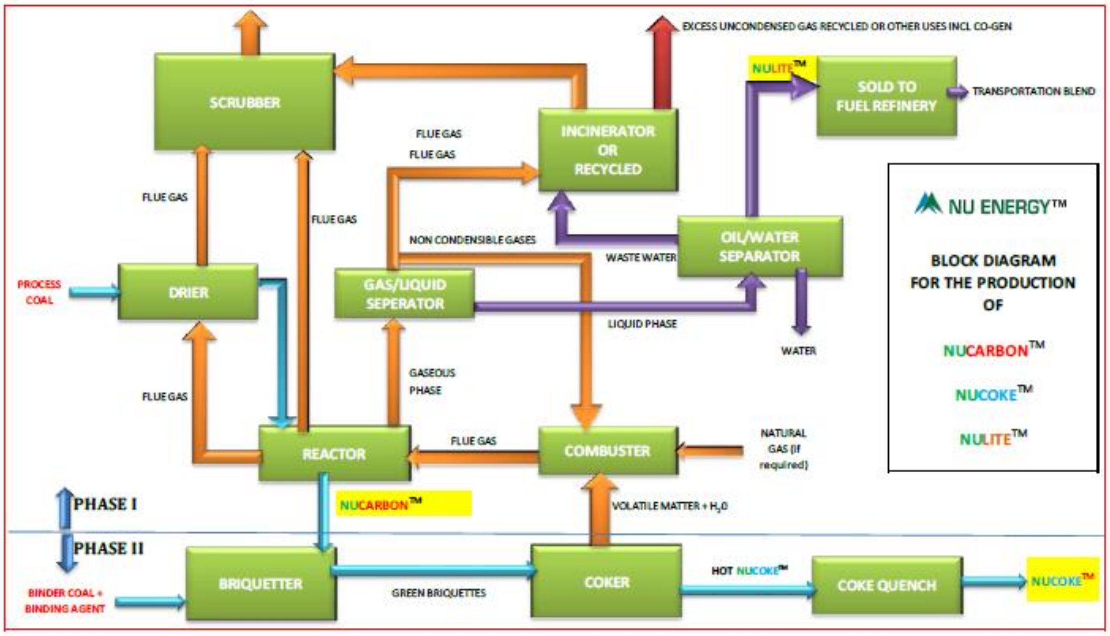

Figure 6. Block diagram of process for formed coke NUCOKE™.

3. Environmental impact

Emissions of particulate matter and raw gas to the environment, associated with charging and discharging operations in conventional ovens, are minimized, as the process is continuous and closed, as a difference with batch and open conventional process. To keep gaseous emissions and particulate matter below admissible limits, an incinerator, a demister and a scrubber are used. CO_2 are small, because moisture and volatile matter are removed from coal. 100% of mercury in coal (70 ppb) is removed to the raw gas. EPA qualifies this process as "*a conversion of the coking type coal into three distinct new fuels forms of enhanced value and such should be classified as fuel conversion plant under 40CFR, Section 52.21 (b)(l)(iii)(q)*" in relation to air quality [3,4].

4. Products and applications

NUCARBON™ is the char, product of the pyrolysis, with high fixed carbon content. Its main features are compared with anthracite in table 3.

Property	**NUCARBON™** Teco Myra coal	Anthracite	Ref.
Moisture (%)	1.3	5.3	[3, 6]
Volatile matter, dry base (%)	8.4	6.9	[3, 6]
Ashes, dry base (%)	9.6	14.9	[3, 6]
Fixed carbon, dry base (%)	82.0	78.2	[3, 6]
Sulfur (%)	0.79	0.65	[3, 6]
Grindability Index (GI)	45-50	45	[3, 6]
Bulk density (kg/m^3)	450-600	839	[6]
Mercury (ppb)	0	70	[3, 6]
Thermal properties			
Lower Calorific Value, dry base (Btu/lb.)	14,354	12,308	[3, 6]
Ignition temperature (ºC)	570	630	[3, 6]
Reactivity, Critical Air Blast (l/min)	0,017	0.039	[3, 9]
Loss on Ignition (LOI)	Smaller	Larger	[3]
Price (USD/t)	0–15*	225-250	[6]

* Price after sales of byproducts (**NULITE™** + clean gas)

Table 3. Properties of **NUCARBON™** and anthracite.

According to data in table 3, **NUCARBON™** is a good alternative to anthracite, for the following reasons:

- Similar proximate analysis and grindability
- No mercury, as it is removed in condensates (anthracite contains 70 ppb); this contaminant is included in the new EPA emission limits
- Has better equivalent thermal properties, promoting combustion at a lower cost

Main applications, replacing anthracite, thermal coal or petroleum coke are [3, 6]:

- Fuel in power stations
- As a carburizer in steel ladles and foaming slag agent in EAFs
- For pulverized coal injection in blast furnaces (PCI).
- As fuel and reducing agent in DRI rotary kilns
- Raw material for **NUCOKE**™
- Absorbing agent for removal of heavy metals in wastewater
- For economical substitution of activated carbon

Commercial organizations that could be interested are mining companies, to add value to their products, and iron & steel corporations, to ensure a reliable supply of **NUCOKE**™ and **NUCARBON™** [6].

NUCOKE™: Formed coke, produced by calcining green **NUCARBON™**, coking coal and binder briquetted mixes. Main properties are summarized in table 4, in comparison with conventional coke [4, 6].

Properties	**NUCOKE**™	Conventional coke
Moisture (%)	2 max	5-7
Volatile matter (%)	0.5-1.0	1.0 max
Ash (%)	7	8
Fixed carbon (%)	92	91
Sulfur (%)	0.6	0.7
Bulk density (lb./cubic feet)	38	29
Stability (%)	61-66	58
Hardness (%)	69	67
CSR, NSC (%)	65-74	55 min
CRI, NSC (%)	24-31	32 max

Table 4. Characteristics of **NUCOKE™** and conventional coke.

NUCOKE™ tests carried out in several iron & steel plants and foundries in the USA, as a replacement for conventional coke, have been satisfactory. The data in table 4 show that quality is similar or exceeds that of conventional coke [4, 6].

NULITE™: Light oil recovered from raw gas generated by coal pyrolysis, containing around 5 % of Benzol, Toluene and Xylene (BTX); high, compared with light oil produced in conventional coke plants (less than 1.5%) [6]. Due to these features, it is usable in oil refineries, as the BTX generated in conventional coke batteries, and it can be mixed with oil in special formulations, to produce gasoline and diesel oil [6].

4. NUCARBON™ project evaluation

Production costs, annual earnings, cash flow along 10 years IRR and ROC are estimated for a production of 50,250 tpa of **NUCARBON™**. Investment is 25 M USD, to be executed in 18 months. The purchase of 50,250 tpa of anthracite is replaced. Prices of coal, anthracite, **NULITE™** and methane are USA 2012 average values. Operating cost (labor and services) is estimated on a 2013 base [6].

NUCARBON™ costs are shown in table 4. Production cost is 111 USD/t; total cost is reduced to zero, as a result of the sales of **NULITE™** and methane. In tables 5 and 6 project earnings, cash flow along ten years, IRR and ROC are presented.

Project data		
Raw materials and products	U/carbon	U/tpa
Consumption of thermal coal (t)	1.0	72,500
Production of NUCARBON™ (t)	0.7	50,750
Production of NULITE™ (Bbl.)	1.0	72,500
Production of fuel gas (M BTU)	3.0	217,500

Costs				
				Cost
Nº		USD/U	T	USD/t NUCARBON™
1.0	Coal	60	72,500	86
2.0	Operating cost	25	50,750	25
3.0	Total cost			111
4.0	Credits			
4.1	NULITE™	100	72,500	-100
4.2	Methane	4	217,500	-12
5.0	Final cost			0

Table 4. NUCARBON™ cost.

Description	USD/year
Savings in anthracite (225-111) USD / t. x 50750 t/year≈	5,800,000
NULITE™ sales (100-0) USD /barrel x 72500 barrels/year	7,250,000
Gas sales (4 -0) USD/M BTU x 217,000 M BTU/year ≈	870,000
EBITDA	13,392,0000

Table 5. Earnings of the project.

	Year									
	1	2	3	4	5	6	7	8	9	10
Investment M USD	-12.50	-12.50								
Profit M USD			13.92	13.92	13.92	13.92	13.92	13.92	13.92	13.92
Net flow M USD	-12.50	-12.50	13.92	13.92	13.92	13.92	13.92	13.92	13.92	13.92
IRR (%)										43.2
ROC (%)										1.8

Table 7. Cash flow, IRR and ROC.

5. NUCOKE™ cost evaluation

Production costs are estimated for a 50,250 t per year plant. Coking coal and binder cost are an average of 2012 USA costs. Operating cost (labor and services) is estimated on a year 2013 base [6].

Raw materials	USD/t	U/0.8 t NUCOKE™	USD/0.8 t NUCOKE™
NUCARBON™		0.6	0
Coking coal	200	0.3	60
Binder	450	0.1	45

Operating cost	16
Total cost USD/0.8 t **NUCOKE**™	121
Total cost USD/t **NUCOKE**™	151.25

Table 8. Estimation of **NUCOKE**™ cost.

Estimated total cost of **NUCOKE**™ is USD 151.25/t, which is interesting in comparison with the average international coke price.

6. Conclusions

- **NUENERGY**™ technology produces commercially **NUCARBON**™ [char] and **NULITE**™ [light crude oil] with a proven process and equipment commercially available, with several tests to guarantee the yield.
- **NUCARBON**™ is a carbon-rich product, which can be applied as a fuel in power stations, for slag foaming in EAFs and as a recarburizer in steel ladles, replacing anthracite or petroleum coke.
- The cost of **NUCARBON**™, after sales of byproducts (**NULITE**™ and gas) is practically zero, what makes the project very attractive.
- **NUCOKE**™ is a product that can be used as fuel and reducing agent in blast furnaces, and as fuel in cupolas, replacing conventionally produced coke at lower cost.
- **NULITE**™ is a process byproduct (light oil) rich in BTX that can be used in refineries, mixed with oil, to produce gasoline and diesel oil.
- The process generates enough gas to satisfy process needs and sale the balance as a byproduct, improving the economical equation of the process.
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