

# Oil Shale

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Oil Shale - sedimentary rock of organic origin, in which the inorganic component prevails over the organic, called kerogen, a type of solid fuels. In appearance shale - layered, less dense, massive, sometimes stratified into tiles rock dark gray or brown .in various shades, when ignited burn smoky flame

inorganic substances and kerogen 50-80% In the dry matter of oil shale contains .(50%(sometimes up to 20-35%

Mineral portion consists of Ca carbonates (mainly), Mg, Fe, silica and clay components (quartz, feldspar and complex aluminosilicates) meet the inclusion ., as well as compounds Ge, Be, Sc, and other rare items $2FeS$

Kerogen contains aromatic, alicyclic, and organic oxygen-and sulfur-containing compounds, practically insoluble in organic solvents

# World Oil Shale Resources

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trillion tons 650 The potential for oil shale in the world, estimated at times more than all the 4 trillion tons of shale oil, that is 26 (equivalent to .(proven reserves of natural oil

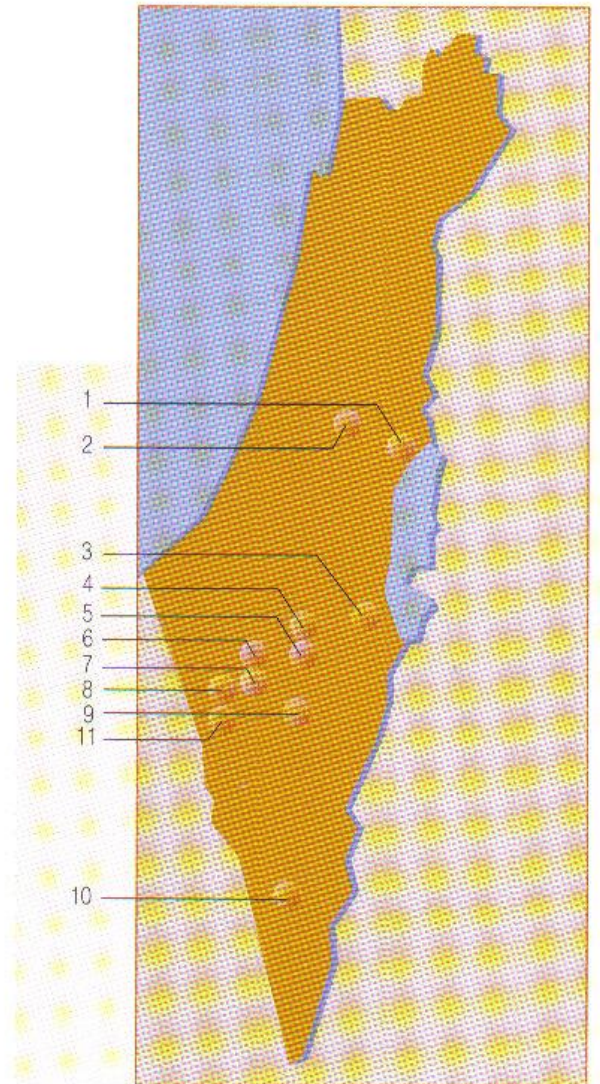
trillion tons shale 20-21 billion tons (430-450 The main resources - about oil) are concentrated in the United States (Colorado, Utah, Wyoming) and are associated with the formation of the Green River. Large reserves of oil shale are in Brazil, Estonia, China, smaller - in Bulgaria, Ukraine, United Kingdom, Russia, Germany, France, Spain, Austria, Canada, Australia, .Italy, Sweden and the former Yugoslavia

billion tons 12 Potential resource of oil shale in Israel is estimated at

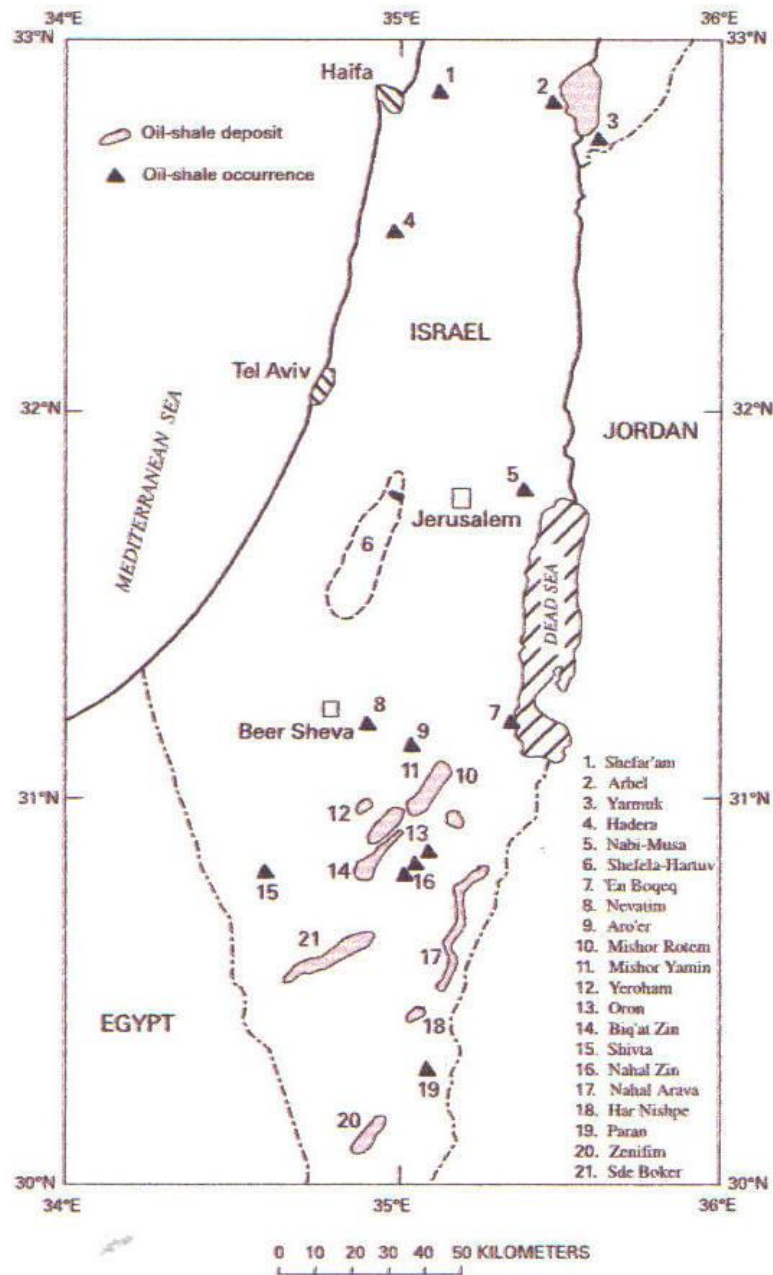
# עתודות של פצלי-שמן בערץ

עתודות ידועות של פצלי-שמן בארץ

המרבץ (מיקום במפה)	כיסוי טפל עובי (מטרים)	עובי (מטרים)	חומר אורגני (%)	כמות (מיליון טון)
נבי מוסא (1)	0-30	25-40	14-18	200
הר-טוב (2)	25-50	150-200	14-15.5	1,100
עין בוקק (3)	30-100	40-60	15	200
מישור רותם (4)	20-150	20-120	11-17	2,260
מישור ימין (5)	20-170	20-120	10-18.5	5,200
ירוחם (6)	70-130	10-50	16	200
אורון (7)	0-80	10-60	15-21	700
שבטה (8)				
צין (9)	5-50	5-30	12-16	1,500
צניפים (10)	30-50	10-60	8	1,000
שדה בוקר (11)	49-150	17-70	15-18	3,000







1. Shefar'am
2. Arbel
3. Yarmuk
4. Hadera
5. Nabi-Musa
6. Shefela-Hartuv
7. En Boqeq
8. Nevatim
9. Aro'uer
10. Misor Rotem
11. Misor Yamin
12. Yeroham
13. Oron
14. Biq'at Zin
15. Shivta
16. Nahal Zin
17. Nahal Arava
18. Har Nishpe
19. Paran
20. Zenifim
21. Sde Boker

# Mishor Rotem Oil Shale Characteristics

## Dry Oil Shale Analysis

Component	%	% OM
Carbon C-org	9.70	66.4
Hydrogen H-org	1.12	7.70
Nitrogen N-org	0.33	2.30
Oxygen O-org	2.13	14.6
Sulfur S-org	1.32	9.00
Total Organic Matter OM	14.60	100
Mineral Matter:	85.40	
Include: - S-pyrite	0.53	
- S-sulfide	0.58	
- CO <sub>2</sub> -carb	23.68	

## Fischer Assay (FA) Data

Component	Yield, %	Remark
Oil	6.23	S – up to 8%
Gas	3.14	H <sub>2</sub> S - 25% (vol)
Pyrolysis Water	2.50	Soluble Sulfates
Solid Residue	88.13	420 kcal/kg HHV

Moisture - 20% (dry base)

High Heating Value (HHV)– 1050 kcal/kg (dry base)

# Various Deposits Oil Shale Characteristics

Deposits	Elemental Composition of OM				Pyrolysis Products Yield, % of OM			
	C	H	O	S	Oil	Water	Solid	Gas
Baltic (Estonia)	77,3	9,8	11,2	1,7	65,0	5,4	13,6	16,0
Leningrad (Russia)	77,7	9,8	11,3	1,2	63,2	5,5	15,2	16,0
Boltino (Ukraine)	68,0	9,3	18,3	1,9	43,3	15,3	28,1	13,3
Thimahtid (Morocco)	70,5	9,3	12,4	7,8	40,7	5,2	21,5	32,6
Green River (USA)	80,9	11,4	6,9	0,8	66,9	8,4	7,9	16,8
Gurkov (Bulgaria)	64,3	10,9	24,8		39,2	10,4	31,1	19,3
Nerke (Sweden)	69,5	7,7	16,8	6,0	28,0	17,0	30,5	24,5
Lothian (Scotland)	63,0	10,1	26,2	0,7	41,0	11,0	37,0	15,0
Render (Australia)	63,1	7,9	28,3	0,7	62,2	1,4	27,7	8,7
Irate (Brazil)	68,1	10,3	17,9	3,7	40,9	9,8	34,1	15,2
Fushun (China)	73,4	8,5	10,6	7,5	36,6	4,0	42,3	17,1
Rotem (Israel)	65,0	7,0	15,4	10,7	37,1	20,9	24,0	17,9
Stuart (Australia)	63,7	9,6	20,4	6,9	32,5	15,5	32,0	20,0
El Lajun (Jordan)	78,9	5,3	1,43	14,3	60,8	7,36	15,2	16,67

# Main Directions of Oil Shale Using

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**Direct combustion to produce heat, with subsequent conversion to electrical energy**

**Thermal conversion into synthetic oil (shale oil) and then processed into synthetic motor fuel**

# Shale Oil Production - RETORTING

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**Oil shale processing, named as rule “Retorting”, is PYROLYSIS process i.e. heating at 400-500C in non-oxygen enviromenal.**

**The Retorting, under optimum circumstances, recovers oil up to 120% FA yield, but the oil produced is inevitably highly unsaturated, that is, containing substantial proportions of olefinic hydrocarbons.**

**This oil is prone to spontaneous polymerization in storage and transport, and requires immediate upgrading by hydrogenation in a separate catalytic hydrotreater to produce a stable, marketable product.**

**Two kind of Heat Carrier for Pyrolysis Process:**

- 1. Gas Heat Carrier**
- 2. Solid Heat Carrier (SHC)**



# Comparison of world oil shale commercial retorting technologies

<b>Retort</b>	<b>Fushun</b>	<b>Kiviter</b>	<b>Galoter Enefit Petroter</b>	<b>Petrosix</b>	<b>Alberta Taciuk</b>
<b>Company</b>	<b>Fushun Shale Oil</b>	<b>Viru Keemia (VKG)</b>	<b>Narva Power, VKG</b>	<b>Petrobras</b>	<b>SPP</b>
<b>Country</b>	<b>China</b>	<b>Estonia</b>	<b>Estonia</b>	<b>Brazil</b>	<b>Australia</b>
<b>Location</b>	<b>Fushun</b>	<b>Kohtla Jarve</b>	<b>Narva</b>	<b>Sao Mateus</b>	<b>Stuart</b>
<b>Oil Shale Feed, t/day</b>	<b>100/300</b>	<b>1000</b>	<b>3000</b>	<b>6200/1200</b>	<b>6000</b>
<b>Particle Size, mm</b>	<b>10-75</b>	<b>10-125</b>	<b>0-25</b>	<b>6-50</b>	<b>0-25</b>
<b>Heat Carrier</b>	<b>Gas</b>	<b>Gas</b>	<b>Ash</b>	<b>Gas</b>	<b>Ash</b>
<b>Oil Yield, % of FA</b>	<b>65</b>	<b>75-80</b>	<b>85-90</b>	<b>90</b>	<b>85-90</b>

## Oil Shale World Using (2009)

Country	Mining, mln t	Electricity, mln t	Oil Production, mln t
Estonia	17.1	14.4	2.7
China	3.8	0.0	3.8
Brazil	2.5	0.0	2.5
Russia	1.0	0.7	0.3
Australia	0.8	0.0	0.8
U S A			
Israel	0.35	0.35	0.0



1918

TALLINNA TEHNIKAÜLIKOOL  
TALLINN UNIVERSITY OF TECHNOLOGY

# China Oil Shale Industry

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The shale oil production increases year by year. In 2011, estimated shale oil production was about 650,000 tones, which is equivalent to about 13,000 bbl/d.

There are 7 oil shale retorting plants, involving Fushun, Huadian, Wangqing, Beipiao, Longkou, Yaojie and Dongning, located in 5 provinces.

Fushun - 220 retorts with the daily capacity of 100 t of oil shale per each retort. The annual shale oil production in Fushun is about 350,000 t. The total annual amount of oil shale processed is about **10 million t**.

**Shale Oil Production Cost is 1500 Yuan/t (240 US\$/t)**

The ATP (Alberta Taciuk Process) unit was imported by Fushun Coal Mining Group and it has been actuated for the cold testing.

Longkou - there is an oil shale retorting plant. The plant has 40 Fushun retorts in two blocks. The first block (20 retorts) was actuated in 2009. The second block (20 retorts) was put into operation in May, 2011. The total shale oil production is about 120,000 t per year. The plant is located near the sea. So, shale oil is sold as marine fuel oil. Longkou Coal Mining Group Company plans to import Enefit-280 technology from Estonia.

# China Oil Shale Industry

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Wangqing - 40 Fushun retorts have been built to produce about 50,000 t of shale oil each year by Longteng Energy Company in, Jilin province. An oil shale power plant was also constructed in 2009. There are 2 circulating fluidized bed boilers with the vapor generation capacity of 35 t/hr (6000 kW of electricity). The oil shale with particle size of less than 10 mm is used for electricity generation.

Yaojie - 8 oil shale retorts installed. The plant has been successfully operated since the end of July 2010. This retort is the square-shaped gas combustion retort. The retorting gas, mixed with air, enters the bottom of the retort and combustion of the gas provides retorting process with heat. The retort has the capacity of 500 tons of oil shale per day. Compared with the Fischer Assay the shale oil yield of the retort is above 80%. The advantages of such type of retort are: simple structure, less capital costs, and easy operation.

In Jimsar County, Xinjiang province, 62 modified Fushun type retorts with the daily capacity of 300 t of oil shale, will be established by Liaoning Chengda Company Ltd. Construction will be finished by the end of this year and retorts will be put into operation.

# China Oil Shale Industry

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Beipiao - 60 Fushun retorts, with the daily capacity of 100 t have been operated since August 2011. Another 24 Fushun retorts, with the capacity of 200 t/d, will be put into operation this year. Because of low oil content (approximately 5%), the only suitable technology for Beipiao oil shale is Fushun retort technology. The plant is economically feasible only because of open-cast mining.

In Huadian, a power station has been operating for 14 years. There are three circulating fluidized bed boilers (CFB) for oil shale combustion. The vapor generation capacity of each CFB is 65 t/h. 30 Fushun retorts produce 50,000 t of shale oil each year. Hong Sheng Energy Company finished the construction and installation of 12 modified Fushun retorts by the end of July 2010. Each retort has the capacity to process 300 t of oil shale per day. In this retort, there are two sections: upper one is cylindrical (like in Fushun retort) and it is used for oil shale retorting; lower one is a square section used for semi-coke cooling. Retorting gas is indirectly heated in the tubular furnace and recycled into upper section to heat oil shale. Semi-coke is used as the feedstock for the power station. Oil shale ash is used for producing building materials.

Professor *Shuyuan LI*

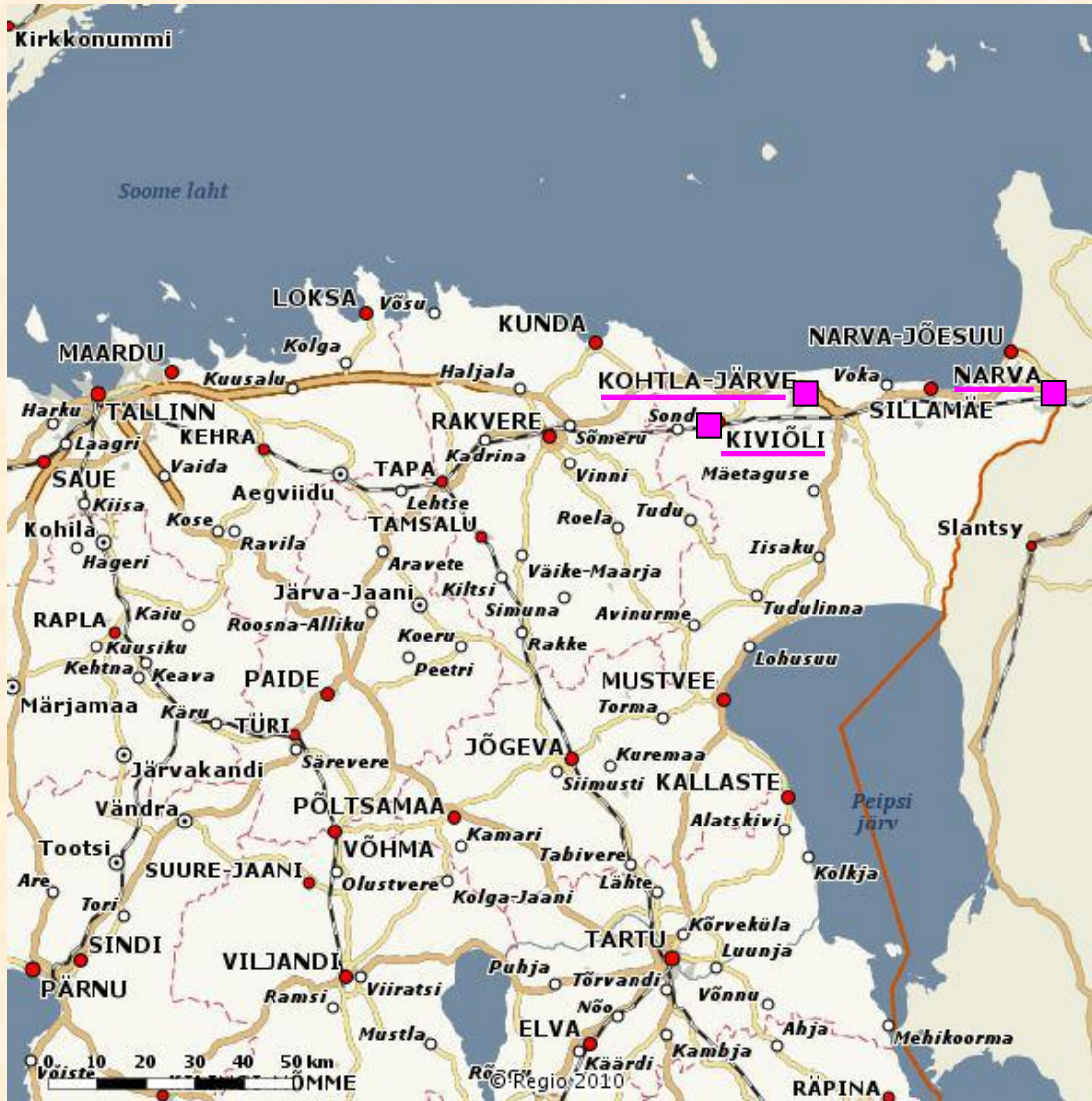
China University of Petroleum, Beijing  
Oil Shale, 2012, Vol. 29, No. 2



## China Oil Shale Using (2012)

Deposits, Plants	Electricity, mln t	Oil Production, mln t	Remark
Fushun		10.0	ATP
Longkou		1.9	Enefit-280
Wangqing	0.6	1.8	
Yaojie		1.4	
Xinjiang		6.2	End 2012
Beipiao		2.0	
Huadian	1.6	1.8	
<b>T o t a l</b>	<b>2.2</b>	<b>25.1</b>	

# Estonia Shale Oil Production Activity



## NARVA

2 GALOTER Units YTT-300,  
modified and named now  
ENEFIT 140,  
1 Unit ENEFIT 280 under  
design and construction

## KOHTLA JARVE - VKG Oil

1 GALOTER Units YTT-3000,  
modified and named now  
PETROTER, put in operation in  
12.2009, has reached nominal  
capacity in July 2011.

**Unit Cost 70 mln.Euro**

## KIVIOLI

3 GALOTER Units YTT-500,  
1 Unit put in operation with  
many problems

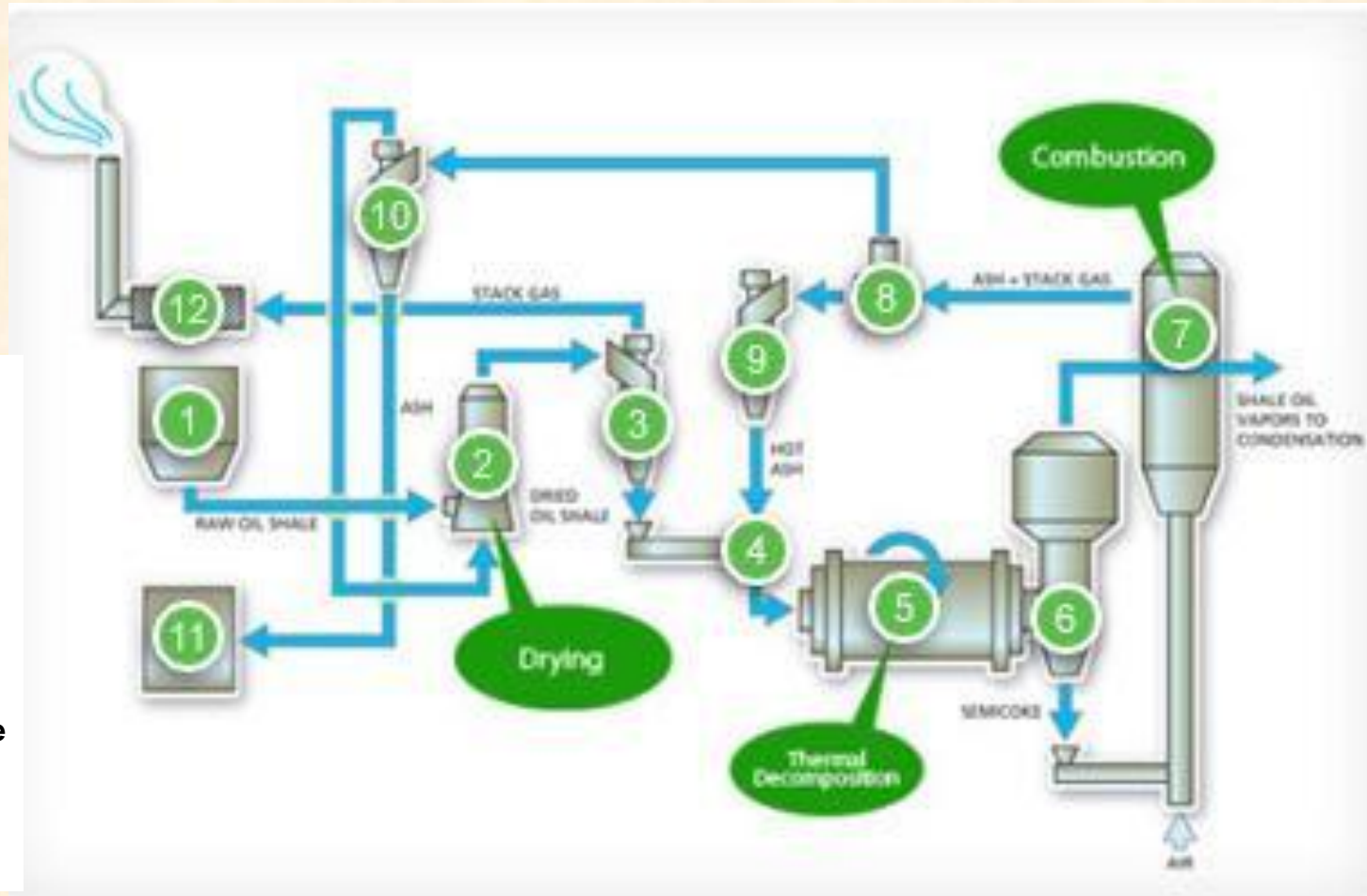
# Galoter Process

The Galoter process is an above-ground oil-shale retorting technology classified as a hot recycled solids technology. The process uses a horizontal cylindrical rotating kiln type retort, which is slightly declined. It has similarities with the TOSCO-II process.

Before retorting, the oil shale is crushed into fine particles with a size of less than 25 mm (1.0") in diameter. The crushed oil shale is dried in the fluidized bed drier (aero fountain drier) by contact with hot gases. After drying and pre-heating to 135 °C, oil shale particles are separated from gases by cyclonic separation. Oil shale is transported to the mixer chamber, where it is mixed with hot ash of 800 °C, produced by combustion of spent oil shale in a separate furnace. The ratio of oil shale ash to raw oil shale is 2.8–3:1. The mixture is moved then to the hermetic rotating kiln. When the heat transfers from the hot ash to raw oil shale particles, the pyrolysis (chemical decomposition) begins in oxygen deficit conditions. The temperature of pyrolysis is kept at 520 °C. Produced oil vapors and gases are cleaned of solids by cyclones and moved to condensation system (rectification column) where shale oil condense and oil shale gas is separated in gaseous form. Spent shale (semi-coke) is transported then to the separate furnace for combustion to produce hot ash. A portion of the hot ash is separated from the furnace gas by cyclones and recycled to the rotary kiln for pyrolysis. The remaining ash is removed from the combustion gas by more cyclones and cooled and removed for disposal by using water. The cleaned hot gas returns to the oil shale dryer.

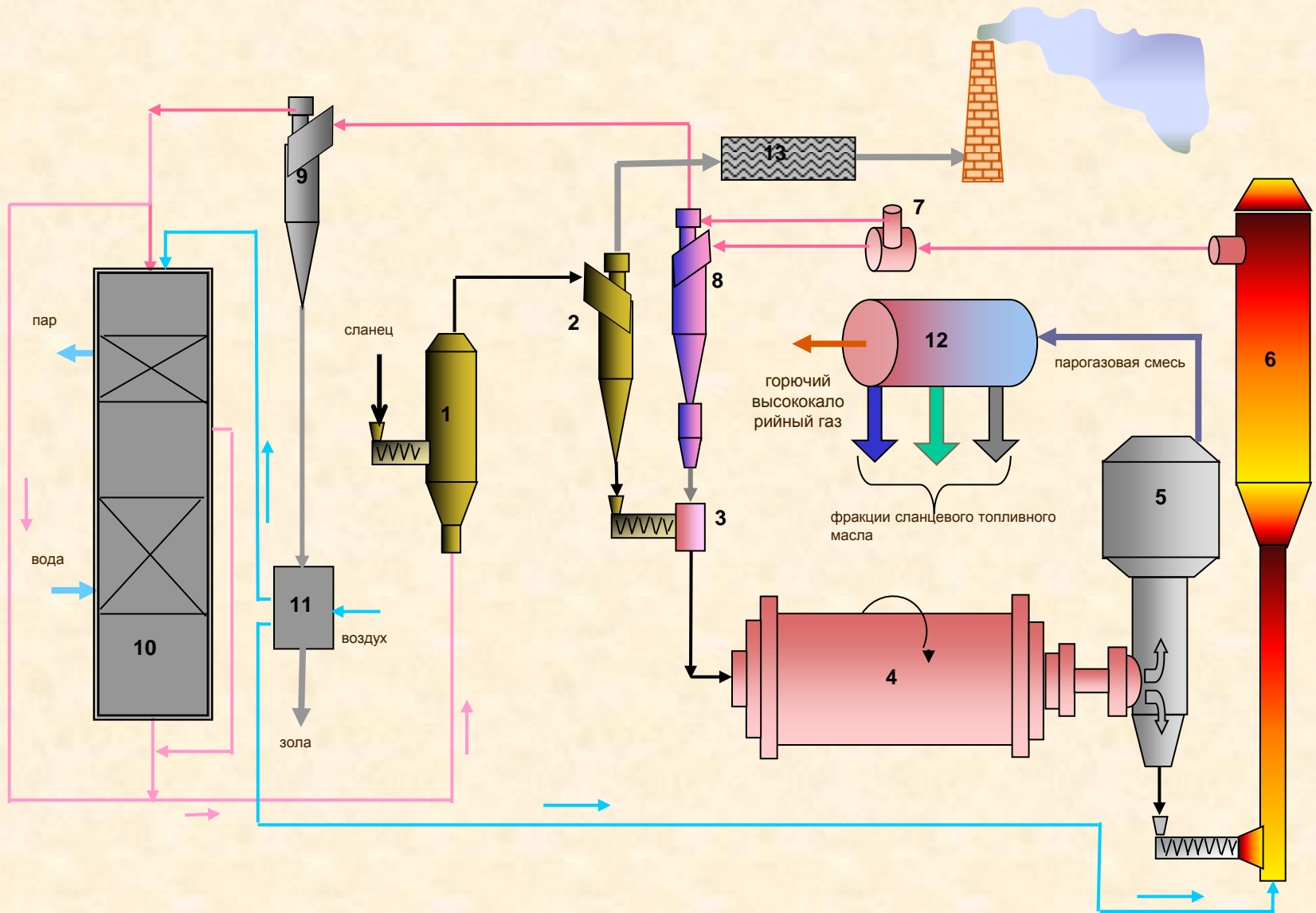
The Galoter process has high thermal and technological efficiency, and high oil recovery ratio. Oil yield reaches 85–90% of Fischer Assay and retort gas yield accounts for 48 cubic meters per ton. Oil quality is considered good, but the equipment is sophisticated and capacity is relatively low. This process creates less pollution than internal combustion technologies, as it uses less water, but it still generates carbon dioxide as also carbon disulfide and calcium sulfide.

# GALOTER Process





# GALOTER Process





# GALOTER Plant



*Eesti Energia Oil and Gas's Enefit 140 Plant in Narva, Estonia. The plant currently operates two production lines, each consuming 140 tons of oil shale per hour. The new Enefit 280 plant (consuming 280 tons per hour) is currently under construction*

# Enefit Process

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**Enefit process is a modification of the Galoter process being developed by Enefit Outotec Technology.**

**In this process, the Galoter technology is combined with proven circulating fluidized bed combustion (CFB) technology used in coal-fired power plants and mineral processing. Oil shale particles and hot oil shale ash are mixed in a rotary drum as in the classical Galoter process. The primary modification is the replacing of the Galoter semi-coke furnace with a CFB furnace. The Enefit process also incorporates fluid bed ash cooler and waste heat boiler commonly used in coal-fired boilers to convert waste heat to steam for power generation.**

**Compared to the traditional Galoter, the Enefit process allows complete combustion of carbonaceous residue, improved energy efficiency by maximum utilization of waste heat, and less water use for quenching. According to promoters, the Enefit process has a lower retorting time compare to the classical Galoter process and therefore its has a greater throughput. Avoidance of moving parts in the retorting zones increases their durability.**

**The Committee on Foreign Investment in the United States (CFIUS) approved the agreement between Oil Shale Exploration Company (OSEC) and Enefit on 15 of March 2011.**

**According to the agreement Enefit acquires 100% of OSEC shares and will therefore become the owner of the largest tracts of privately owned oil shale properties in Utah. Enefit is planning to construct an oil shale plant with a capacity of 57,000 barrels of shale oil per day at full production.**

# Galoter & Enefit Commercial Use

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Two Galoter retorts built in 1980 are used for oil production by the Narva Oil Plant, a subsidiary of the Estonian energy company Eesti Energia. Both retorts process 125 tons per hour of oil shale. The annual shale oil production is 135,000 tons and oil shale gas production is 40 million cubic meters per annum. The company is building a new plant employing its newer Enefit process with a processing capacity of 2.26 million tons of oil shale per year and producing 290,000 tons of shale oil and 75 million cubic meters of oil shale gas. It is planned to become operational by 2012. In addition, Eesti Energia plans to begin construction of a similar Enefit plants in Jordan by 2015 and in USA by 2017.

VKG Oil, a subsidiary of Viru Keemia Grupp, constructed a new Galoter retort (Petroter) at Kohtla-Järve that is similar to the two retorts operating at Narva. The basic engineering of the retort was done by Atomenergoprojekt of Saint Petersburg. The basic engineering of the condensation and distillation plant was done by Rintekno of Finland. The plant has a processing capacity of 1.1 million tones of oil shale per year and it produces 100,000 tones of shale oil, 30 million cubic meters of oil shale gas, and 150 GWh of steam per year. Operation started in December 2009.

**Unit cost, according to Estonian Press-Information, is €70 million.**

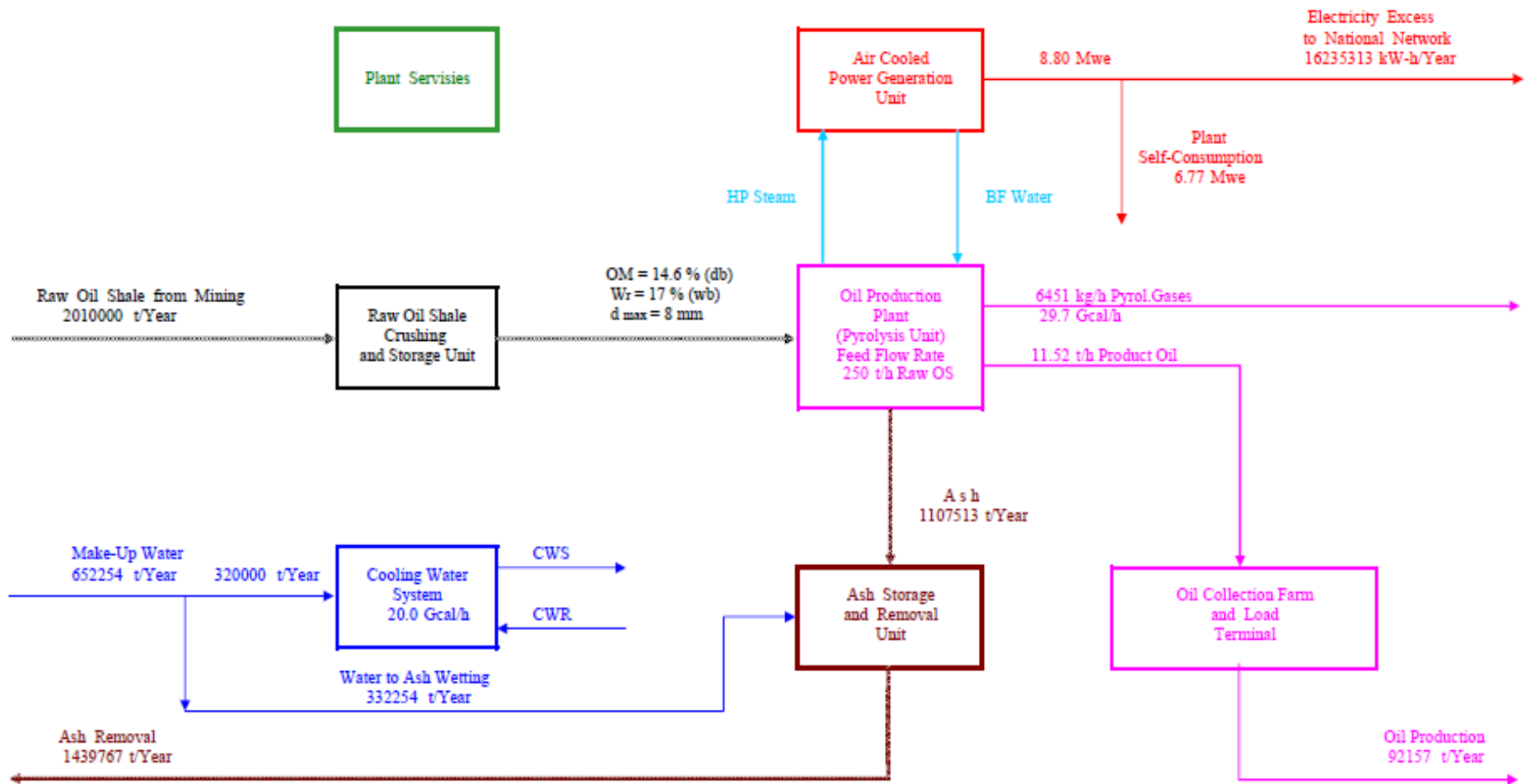
The company plans to start construction of the second Petroter plant in 2012.



# PAMA Shale Oil Production DEMO Unit

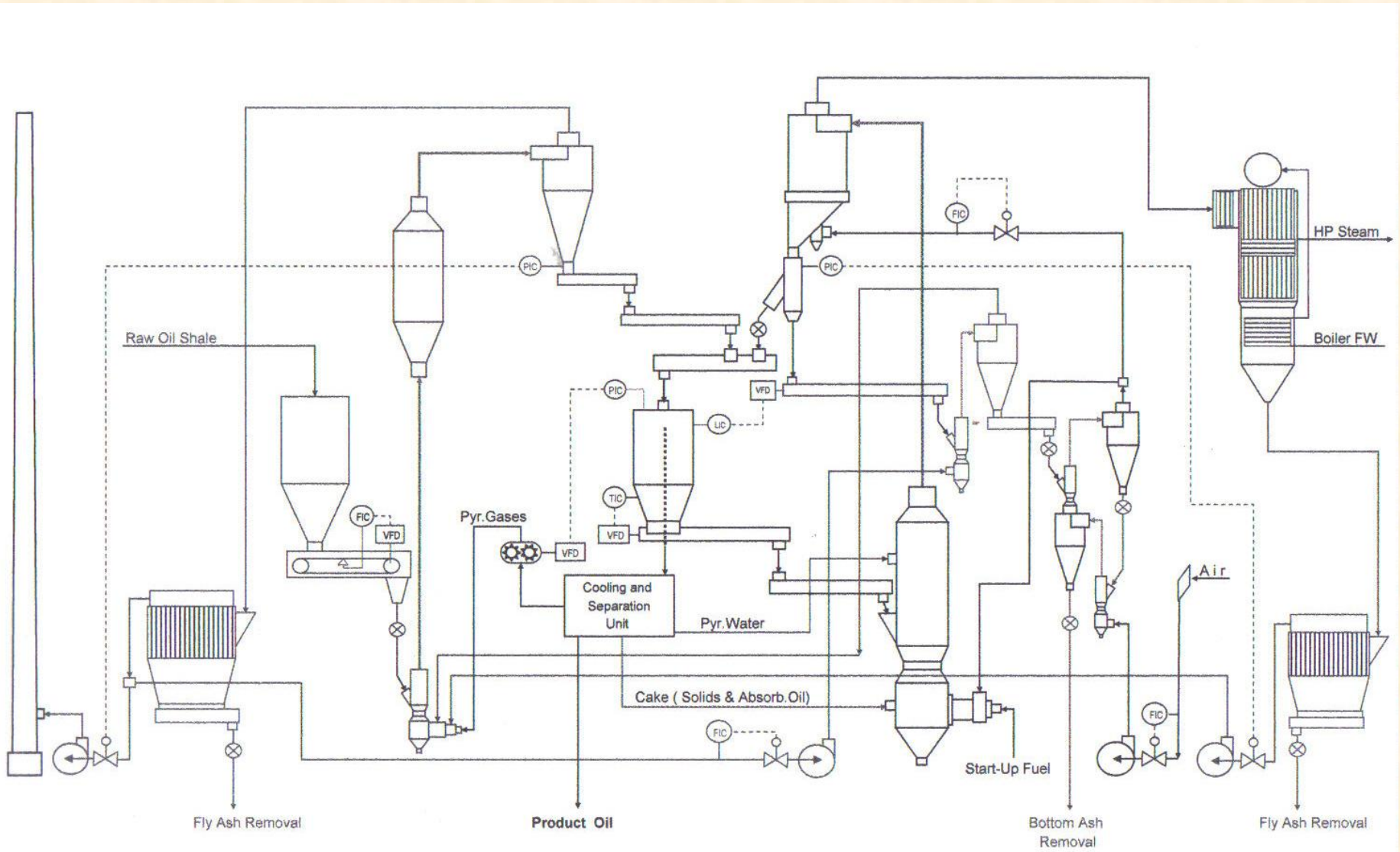


# PAMA Shale Oil Production Industrial Unit Block Diagram





# PAMA Shale Oil Production Industrial Unit





# Estonian Oil Shale Electricity Production

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## Narva Power Plants:

1. Balti Power Plant - 765 MWe installed Capacity
2. Eesti Power Plant - 1615 MWe installed Capacity

All Steam Boilers use the pulverized combustion (PC) technology.

In 2003, the Unit 11 of Balti Power Plant was reconstructed (Foster Wheeler) to use the circulated fluidized bed combustion (CFBC) technology, which is more efficient and environmental-friendly (lower SO<sub>2</sub> and CO<sub>2</sub> emissions) than PC technology.

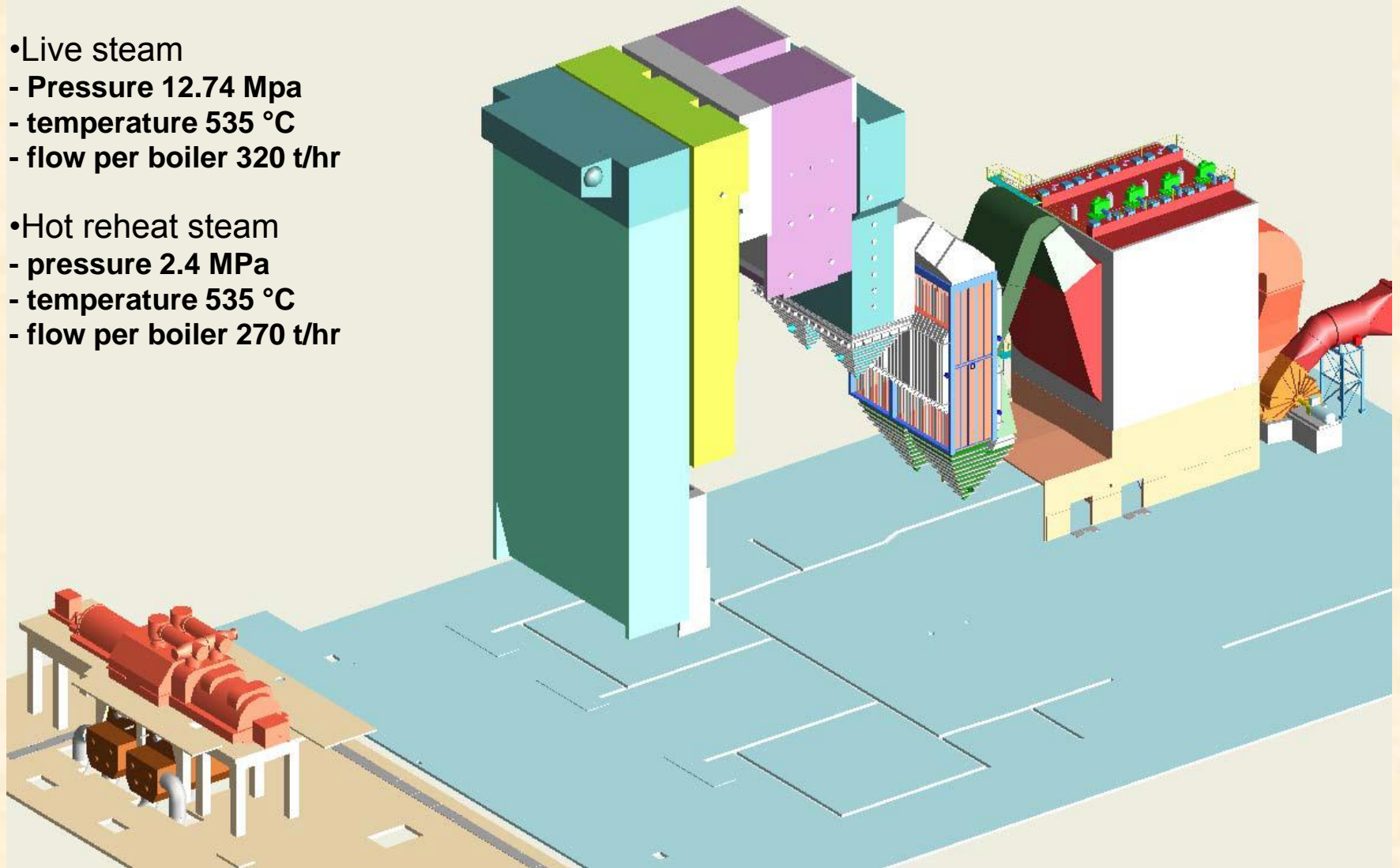
On 14 January 2011, Narva Power signed a contract with the French power engineering company ALSTOM for construction of the new power plant next to existing Eesti Power Plant. The **€950 million contract foresees construction of two 300 MW oil shale-fired units**. The units will utilize circulating fluidized bed boiler technology.

According to the contract, a first unit of **300 MW will cost €540 million**. There is an option for a second unit of **300 MW for €410 million**. The first unit will be completed by 2015. A decision on construction of the second unit will be made in 2012

# Narva power plants CFB Boiler

FOSTER WHEELER

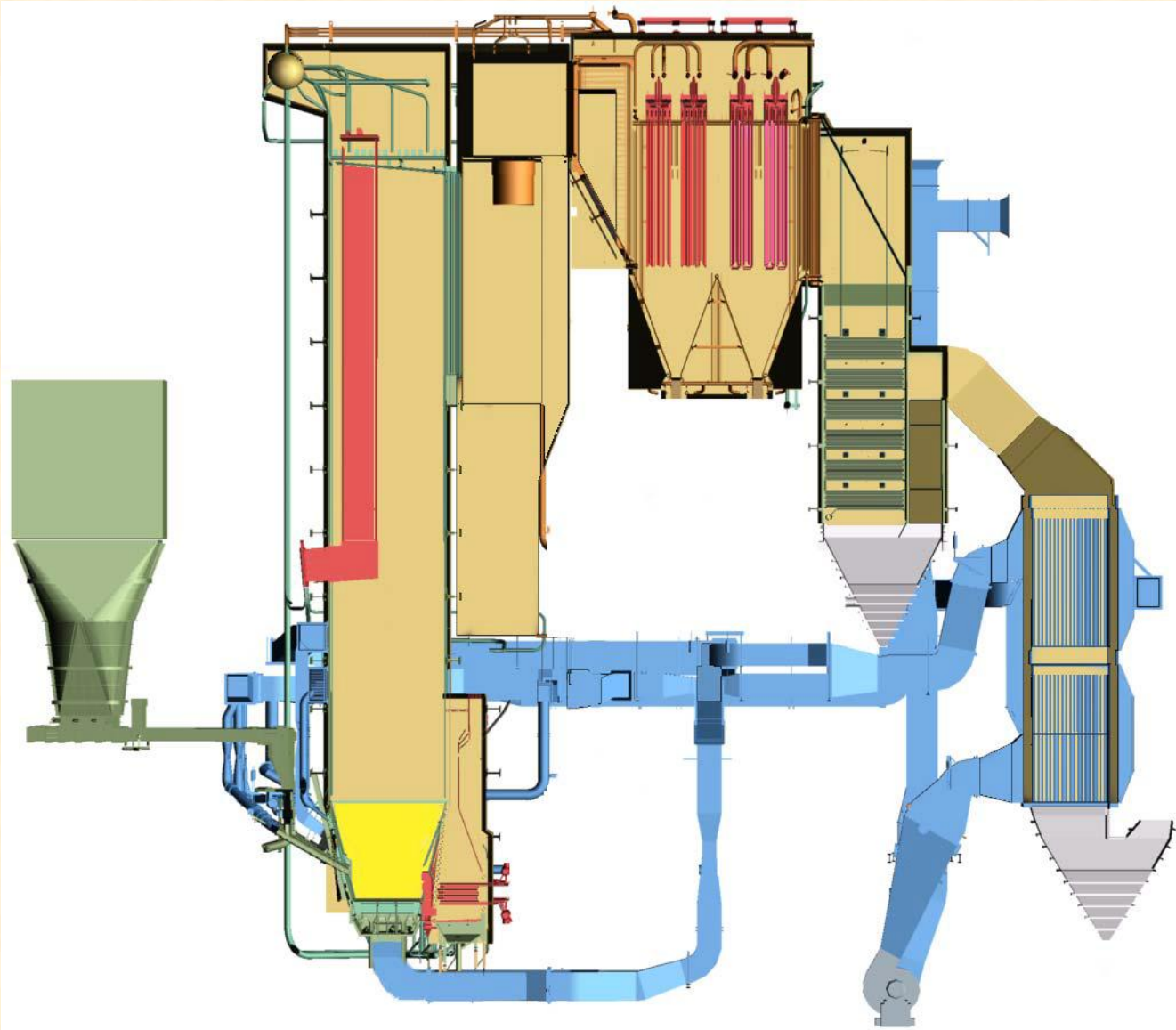
- Live steam
  - Pressure 12.74 Mpa
  - temperature 535 °C
  - flow per boiler 320 t/hr
- Hot reheat steam
  - pressure 2.4 MPa
  - temperature 535 °C
  - flow per boiler 270 t/hr





# Narva power plants CFB Boiler

FOSTER WHEELER





# PAMA Oil Shale Power Plant Steam Boiler

## DEMONSTRATION BOILER - PROCESS DATA

### Steam data

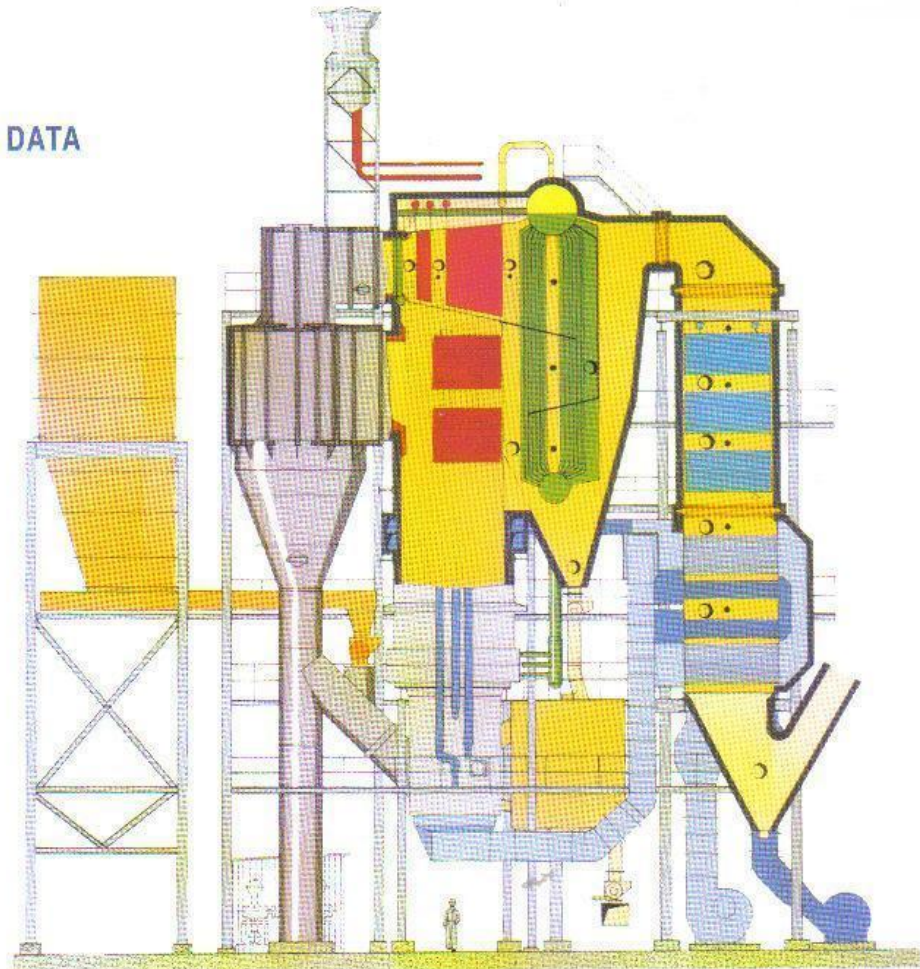
Total Heat Output	41 MW th
Steam Flow	13.9 kg/s
Steam Pressure	43 bar
Steam Temperature	480° C

### Fuel Data

Oil Shale	
Organic Matter	13.6 - 16%
Sulphur	1.1 - 1.7%
Moisture	16 - 22%
Ash	44 - 50%
Lower Heating Value	3.155 MJ/kg

### Design Performance

Furnace Temperature	800° C
Flue Gas Exit Temperature	155° C
Feed Water Temperature	105° C
Boiler Efficiency (DIN)	83.7%



Cross-section of the Demonstration Boiler

# Israeli Oil Shale Other Activities

There were some attempts to erect the Industrial oil shale firing Power Plant: both from IEC by international bid, and from Independent Power Producers (NRG, Mid-Atlantic etc). But these attempts for the different reasons have not crowned success.

Israel Electric Company had executed experimental runs of pressurized fluidized-bed combustion (PFBC) in the ABB Carbon pilot facilities (Opposite Combined Cycle).

AFSEK (Israel) has developed “Hom-Tov” process that includes combined oil shale processing together with heavy oils or refineries bottom residue at temperature 450-500°C and pressure 5-6 Bar; oil shale- oil residue ratio 1:3. Experimental runs in the small batch unit were executed, to day the company continues its activity with plan to erect continuously operated pilot.

ORMAT (Israel) together with ORGRES (Ukraine) had developed SHC pyrolysis process with the idea to direct the obtained pyrolysis products (gas and oil-water vapors mixture) straight way to the steam boiler burner; by such a way the boiler is liberated of ash huge amounts. The company had planed the project for Oron oil shale deposit. The project was stopped, the reasons are not known.

DARICOM (Israel) brought interest to shale oil produced in PAMA to use it for Ichtyol (Ammonium Salt of Sulfonated shale oil) – special pharmacy for therapeutics use in dermatology, e.g. acne and psoriasis as well as in orthopedics. It should be underlined that sulfur rich shale oils only are suitable for Ichtyol producing. DARICOM even had plans to buy PAMA pilot facilities, but the negotiations had not crowned success.

SSOil (Sand & Shale Oil Corporation - USA) has reported about “underground topochemical synthesis of oil and gas from oil shale” feasibility tests conducted in 2005-2006 at the Negev pilot plant, which consists of a 73 meter-deep vertical well accommodating pipes of diameter 7-13 inch, an immersion diesel burner, a burner air fan, the absorber with a re-circulating pump, the spray trap, the petroleum storage volumes, the tail gas fan, and an exhaust pipe for combusting the shale gas. More details aren't known.

IEI (Israel) – Underground oil extraction from Adulam oil shale deposit.

RAO EES (Russia) – Shale Oil Production Plant + 150 MW Power Plant. **Project Cost 230 mln.US\$**

Northwood Exploration to Israel (NEI)

# 10000 kcal LHV Fuels Combustion

10000 kcal LHV  
Methane 0.84 kg

Air 14.3 kg



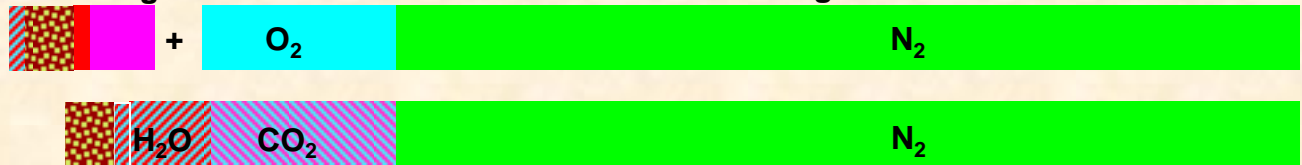
10000 kcal LHV  
Dies.Oil 0.99 kg

Air 14.3 kg



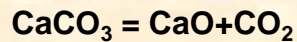
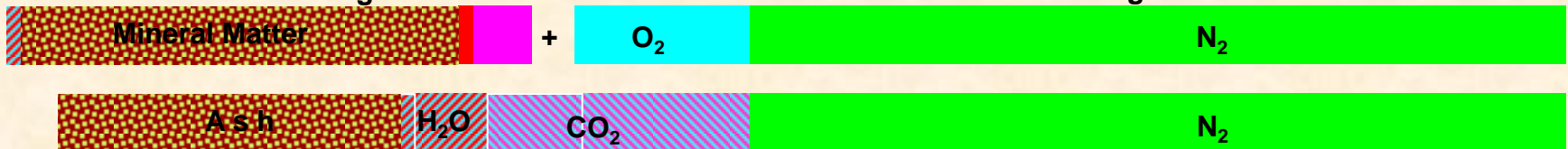
10000 kcal LHV  
Coal 2.0 kg

Air 14.3 kg



10000 kcal LHV  
Oil Shale 8.0 kg

Air 14.3 kg



# 10000 kcal LHV Fuels Combustion

10000 kcal LHV  
Methane 0.84 kg

Air 14.3 kg



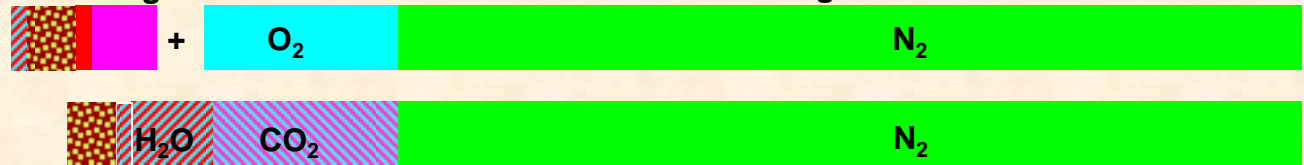
10000 kcal LHV  
Dies.Oil 0.99 kg

Air 14.3 kg



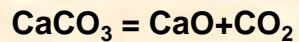
10000 kcal LHV  
Coal 2.0 kg

Air 14.3 kg



10000 kcal LHV  
Oil Shale 8.0 kg

Air 14.3 kg





# Oil Shale Gas

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**Shale Gas** is natural gas (mainly methane) formed from being trapped within shale formations. Shale gas has become an increasingly important source of natural gas in the United States over the past decade, and interest has spread to potential shale gas in the rest of the world. In 2000 shale gas provided only 1% of U.S. natural gas production; by 2010 it was over 20%.

Shale Gas production (mining) is based on:

Horizontal Drilling - lateral lengths up to 10,000 feet (3,000 m) within the shale, to create maximum borehole surface area in contact with the shale.

Hydraulic Fracturing – water and chemicals for shale permeability increasing to create extensive artificial fractures around well bores and to allow significant fluid flow to a well bore

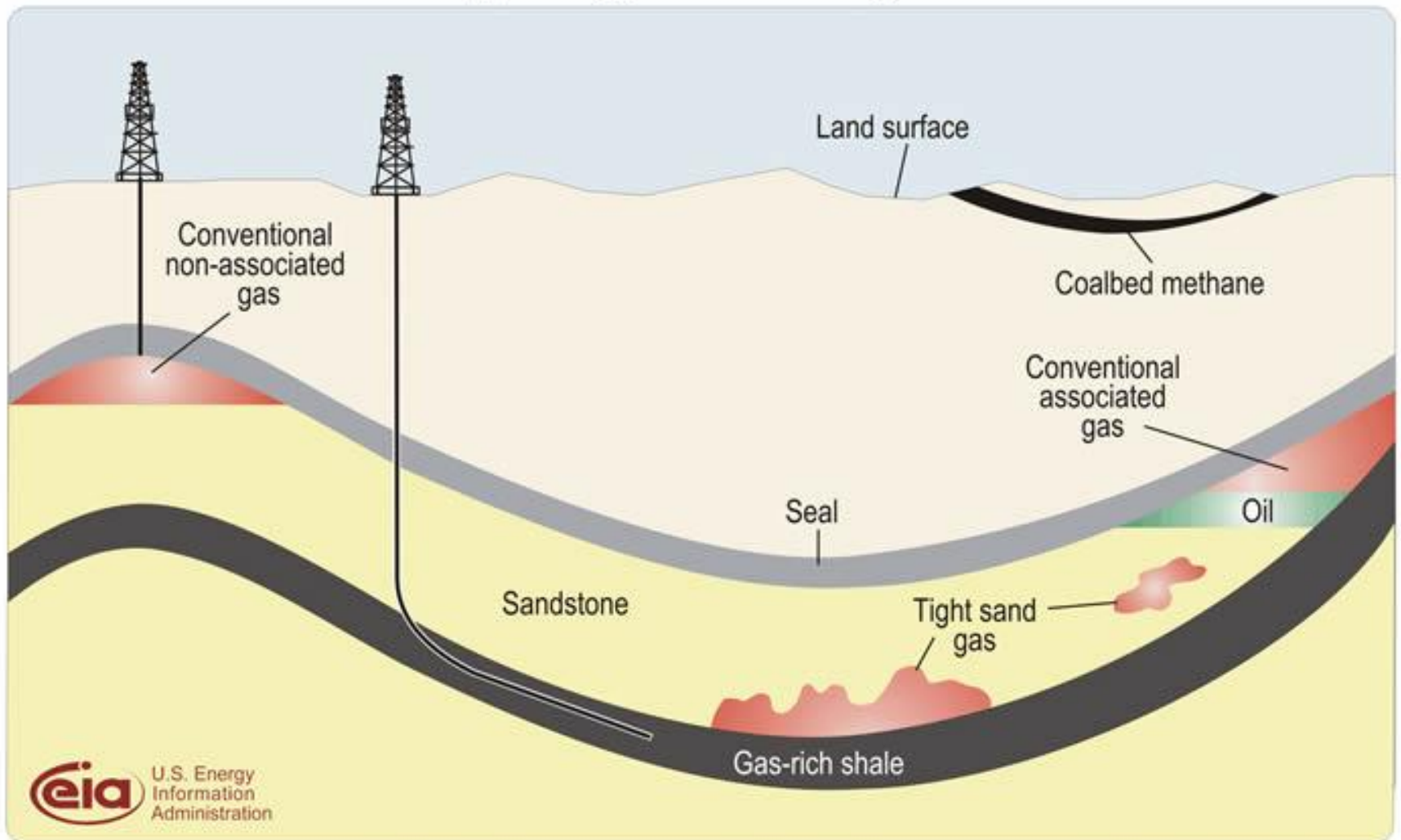
Seismic Modeling 3D GEO

The same technology is used for production of coal-bed methane. While shale gas ( ), but due to the opening of large  $2/ \text{km}^3$  billion  $\text{m}^3$  0.2 - 0.2 is found in small amounts ( .areas can receive a significant amount of this gas



# Oil Shale Gas

Schematic geology of natural gas resources



# Oil Shale Gas

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Large-scale industrial production of shale gas was launched by Devon Energy in the drilled the 2002 s, the field Barnett Shale, which in this field in 2000U.S. in the early first horizontal well. Due to the sharp increase in its production, called the media 745.3 , the U.S. became the world leader in gas production (2009"gas revolution", in were non-traditional sources (coal bed methane and 40% billion cu m.) with over .(shale gas

By the beginning of 2012 the price of natural gas in the U.S. fell to a level significantly below the cost of production of shale gas, resulting in the largest player in shale gas - the company Cheasapeake Energy - announced a production cut by 8%, and the capital investment in drilling - 70 %.

As a result of the growth of shale gas terminals to import liquefied natural gas generated in the U.S., remained inactive. They are currently being refurbished for gas exports

# Oil Shale Gas World Deposits

