

CASE STUDIES ON ALTERNATIVE FUEL CONVERSIONS

CFD Guides Design of Biomass Boiler Retrofit to Increase Capacity by 25% and Decrease Ash Carryover by 60%

Computational fluid dynamics (CFD) analysis supported the design optimization of a wood-fired furnace that was tested to operate with a 25% capacity increase with a 60% decrease in particulate emissions. The CFD modeling studies illustrated the potential operational improvements and increased the confidence levels of a successful set of boiler modifications. The combined use of CFD modeling with traditional boiler design methods were particularly effective for assessing the retrofit potential of an older stoker furnace. Proven retrofit design experience and a detailed baseline testing program that examined all aspects of the boiler equipment were key attributes to the award of a contract to ALSTOM Power Inc. (ALSTOM) for the modification of a 1975 vintage travelling grate stoker boiler located at a paper mill in Louisiana. When considering investing

in upgrading an older boiler, the condition of the different components in the boiler system, combined with the fuel and mode of operation made it difficult to accurately quantify the performance to be gained by a retrofit. ALSTOM solved this problem by using CFD analysis to simulate the performance of the existing boiler, and then modeled the performance of

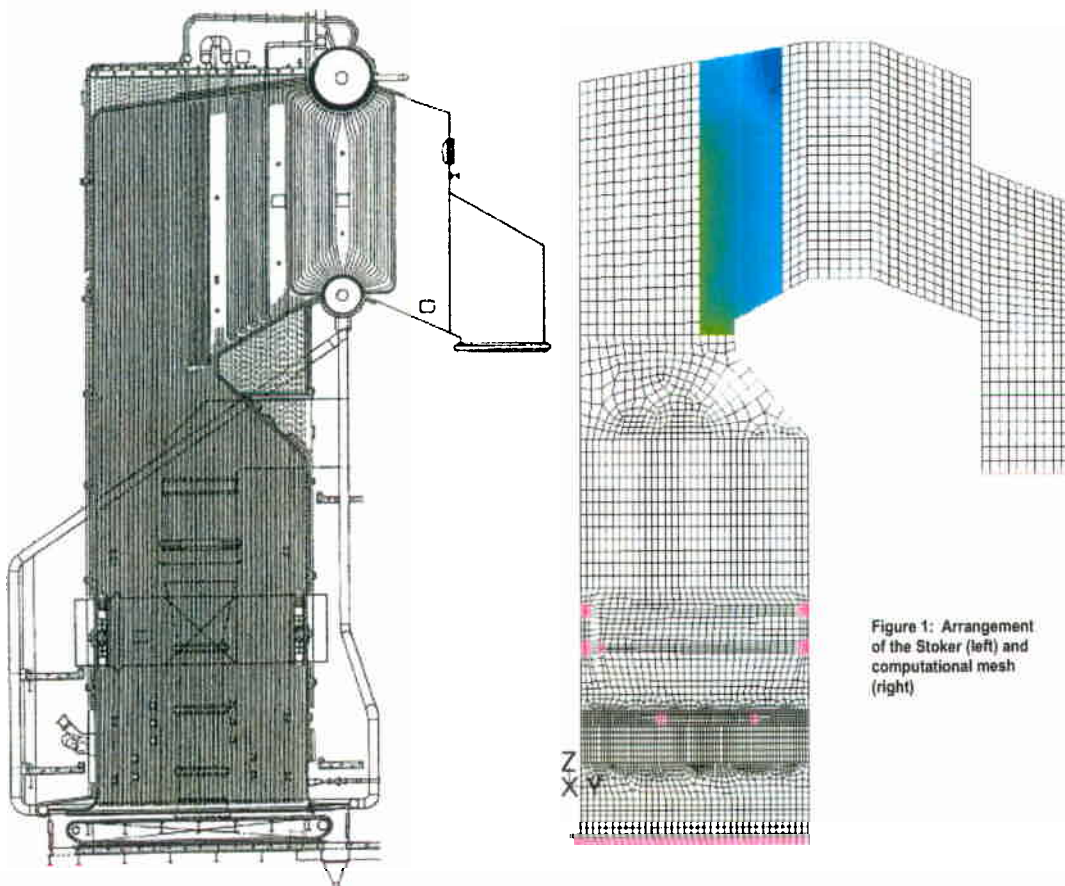


Figure 1: Arrangement of the Stoker (left) and computational mesh (right)

the new system. The results helped identify limitations of the baseline system and how the modifications would improve the performance. "With CFD, ALSTOM was able to illustrate to the mill that the new design represented a significant improvement and was a wise investment. When both the customer and the supplier team up to gather all the CFD model inputs, everyone benefits. Things that people assumed might be happening suddenly become more tangible. The goal was to satisfy the customer and help them to be able to operate their equipment more efficiently," noted Paul Chapman of ALSTOM's Power Plant Laboratories.

ALSTOM's parent is a global specialist in energy and transport infrastructure. It serves the energy market through its activities in the field of power generation, and the transport market through its activities in rail and marine. In fiscal year 2002/2003, it had annual sales in excess of 20 billion Euros and employed approximately 100,000 people in more than 70 countries. It has supplied almost 20 percent of the world's total installed capacity in power generation equipment.

Upgrading wood and biomass-fueled boilers

There are hundreds of wood and wood waste boilers in operation in the US that serve the important role of providing process steam by burning low-grade wood wastes associated with wood and paper processing. These boilers are required to burn a changing mix of wood, wood wastes, hog fuel, and other various solid and gaseous waste streams. With the rising cost of energy, and the desire to reduce gaseous and solid emissions, previously overlooked power boilers are receiving more attention. Many of these older units are now potential candidates for revitalization. Modernization can provide many benefits, including increased steam capacity, higher boiler efficiency, lower gas and solids emissions, and decreased operating and maintenance costs. While these objectives are clear, the task of quantifying a significant renovation that often involves modification of pressure components boils down to economic justification. Given the range of different style boilers and the unique conditions at each site, prediction of performance and calculation of investment payback remains difficult.

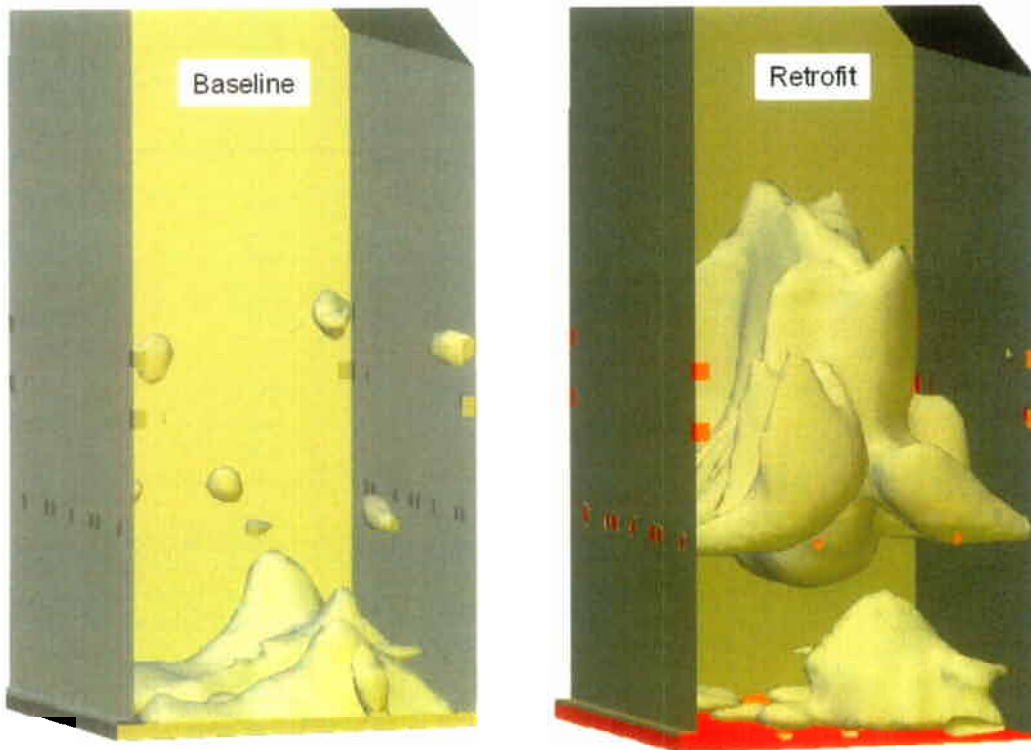


Figure 2: Iso-surfaces of turbulence levels for the original and retrofit firing conditions

"In the initial phases, an engineering assessment is made to develop a proposal," according to Dave Gadai, director of pulp and paper engineering for ALSTOM's Windsor, CT. operations. "While the upgrade usually involves a modification of the boiler's combustion air system, it is actually a total combustion system upgrade. Because each retrofit is different, all of the subsystems - furnace geometry, air system equipment, fuel properties and handling equipment, and the combustion grate

system- must be studied. We can make some estimation of the impact of these factors on the performance of the boiler, but using CFD helps us better predict the combined impact of all suggested modifications,” says Gadai. Adds Chapman, “In generating a stoker boiler model, we work with engineering to quantify the inputs needed to generate a reasonable CFD representation. Some details and various flows are not readily available. That poses a challenge. Older units are particularly troublesome because they lack good flow measurement devices and monitoring equipment.”

ALSTOM was asked to upgrade a 1975 vintage VU-40 stoker boiler that occasionally experienced opacity problems when firing 100 percent hog fuel. It also had a pattern of erosion-related tube leaks when operating at higher loads, and carbon loss with high excess air. Carbon monoxide levels were estimated to be quite high at this unit.

When management at this mill asked for a study that would document performance improvements after a retrofit, ALSTOM decided to present a more precise evaluation by running ‘before’ and ‘after’ CFD simulations. The CFD model of the boiler produced velocity, temperature, species concentrations, and other variables throughout the solution domain for a specific set of input boundary conditions. As part of the analysis, a designer could change the geometry of the furnace or the boundary conditions

and study the effect on the gas flow patterns or temperature distributions. CFD also can provide relative trends on variables such as particulate carryover or emissions.

Fluent Inc., which is located in Lebanon, New Hampshire, licenses a complete set of tools for analyzing fluid flow, heat transfer and combustion. ALSTOM's Power Plant Labs, which is an R&D center supporting the many different power generation businesses globally, has performed an extensive collection of combustion and heat transfer simulations to study and improve the power generation systems and components that ALSTOM supplies. In addition, for many years ALSTOM has collaborated with Fluent to suggest improved submodels and capabilities for the FLUENT software. Because of the diverse range of fuels that are fired in different modes, Fluent's standard code needed to be modified to more accurately describe pulverized coal and other fuels. The CFD modeling

experts at ALSTOM often encounter situations that require the development of custom code in the form of User Defined Functions (UDFs) that are connected to the solver. Fluent's suite of software tools, including mesh generation, parallel solver capabilities and efficient post-processing are fully utilized at Power Plant Labs.

The successful retrofit of this particular stoker boiler started with a CFD analysis of the existing boiler, shown with the

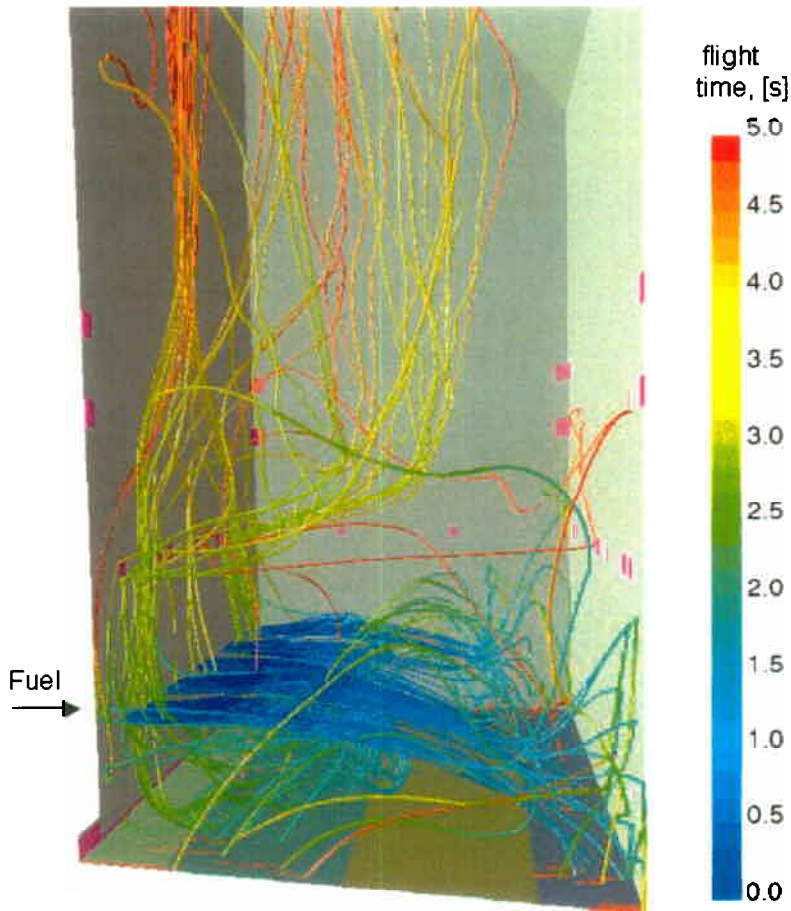


Figure 3: Wood particle tracks colored by residence time for the retrofit case

computational mesh in Figure 1. CFD meshes were developed for both the baseline and retrofit system designs. The baseline system had a series of small ports on the two sidewalls to inject air above the grate where wood particles burn on a traveling grate stoker. In addition to the sidewall air injection, two separate ducts fed corner tangential windbox assemblies for additional overfire air and support fuel. A separate fan was used to recycle cinders collected in hoppers on the back end of the boiler, injecting them through nozzles in the rear wall into the lower combustion zone. Bark was injected at the front of the boiler by five mechanical distributors spaced across the front wall. A relatively coarse unstructured grid of 220,000 cells was used, consisting of all hexahedral elements. The cells were smaller near the overfire air injection nozzles to provide additional detail of the mixing process. The upper furnace was represented with larger cells. If required, the mesh could be adapted with FLUENT's solution-based adaption tools.

Inputs for the CFD model

After creating the furnace geometry for the CFD analysis of the boiler, specific inputs needed to be determined. A sample of the fuel was screened and analyzed to determine the heating value and chemical composition. With the bark firing rate known by the plant, the chemical reaction and combustion model settings could be prescribed. For the fuel injection representation in the CFD model, eight particle size groups were defined and prescribed at each of the five distributors, with mass distribution to the different distributors weighted according to the actual feeder speeds used during the baseline test conditions. In addition to the bark, the char recycle flow rates were estimated. This pneumatically injected char and ash was divided uniformly to the eight injection nozzles. These feeds were assigned particle size distribution and composition that was determined from laboratory analysis.

Estimating and prescribing the air entering the boiler is important, but often difficult to do. Many of the different air inputs are not monitored during operation. For example, the total air to the stoker might be measured with a flow orifice, but the **distribution of air to the various sections of the stoker**

is not readily apparent. To generate a more accurate representation of the baseline operating conditions, measurements and observations were recorded and discussed before running the baseline case. Some of the air distribution was determined using pitot tubes to measure air flows in supply ductwork. At the outlet of the furnace, sample grids measured gas composition on both sides of the air heater. During the testing phase, some additional mechanical degradation was found, allowing ambient air to leak into the furnace. These flows were estimated and also included as part of the total combustion air in the CFD model. The efforts expended on accurately configuring the model inputs increase the overall cost of the modeling effort, but improve the accuracy of the model, and can provide ALSTOM with the opportunity to fix other problems that might be missed by the initial assessment.

For the superheaters, boiler bank, and economizer sections, bulk heat extraction rates were determined from ALSTOM's performance measurements and calculations. Waterwall heat transfer coefficients and water side temperatures were prescribed in conjunction with wall emissivities. Gas radiation properties were calculated based on composition particulate concentrations. With the model inputs well established, the baseline configuration was run and converged. At this point the retrofit air system nozzle arrangements were compared to the baseline case.

The baseline results indicated a flow maldistribution with a stream of fuel rising up the rear wall without effective interaction with the overfire air jets. This plume at the rear wall remained segregated in the upper furnace and was low in oxygen. Char particles were elutriated from the stoker bed and not fully burned in the lower furnace. The sidewall jets had only a minor impact on mixing. The tangential nozzles imparted some swirl to the rising gases, however their elevation was too high in the furnace for optimal combustion. The analysis of particle burning patterns was corroborated by visual inspections through ports in the upper furnace and in-furnace flame cameras. Fuel particles along the back wall were lifted up and floated out of the boiler without being completely burned.

Results

After establishing a baseline CFD model, different retrofit arrangements were modeled and examined by comparing velocity distribution, gas composition, temperatures, and particle trajectories and residence times. “It was clear that we needed to increase the overfire mixing effectiveness,” says Chapman. “So one of the first things we looked at was adopting the HMZ™ design.” This air system has a partially interlaced configuration consisting of offset pairs of large versus small nozzles to control the penetration distance and establish high turbulence levels in the center zone. Analysis of the model with the HMZ™ system showed a much more uniform O₂ distribution and penetration of the jets to the center, with more intense combustion in the lower furnace to increase the bark drying rates on the stoker. Instead of a rising plume of fuel against the rear wall, the channel was centralized, allowing the gases to mix thoroughly. With the representation of the stoker fabric seal and modified air distribution, entrainment levels from the stoker were reduced. This kept the fuel particles on the grate longer, increasing the residence time and particulate concentration in the upper furnace. The combination of the high performance overfire air design with the stoker fabric seal represented a very significant improvement potential compared to the baseline. Figure 2 shows a comparison of the turbulence levels for the baseline and final design. All of the modeling results suggested that the boiler performance would be quite dramatic.

On the basis of these predictions, plant management decided to proceed with the retrofit and the new air system and fabric stoker seal were installed. An illustration of the wood particle trajectories for the

final design appears in Figure 4. After the modifications, performance tests confirmed a significant increase in boiler capacity on biomass firing. Prior to the upgrade, the boiler was capable of only 280,000 lb/hr steam, firing a high moisture level fuel. When the moisture level dropped, the capacity achievable increased to 350,000 lb/hr. At this load, the boiler suffered from high erosion and the boiler operation could not be maintained without tube failures. After the upgrade, the boiler biomass firing capability increased to 350,000 lb/hr for high moisture fuel and up to 480,000 lb/hr for low moisture fuel, representing a 25 percent minimum capacity increase. Carbon monoxide levels after the retrofit were reduced from over 1000 ppm to 260 ppm. A net reduction of 60 percent in the pre-retrofit flyash disposal rates, measured in truckloads, was also observed.

Summary

CFD modeling was an important element of this project and allowed the retrofit performance of this unit to be predicted with reasonable accuracy. The combination of CFD modeling with extensive boiler designs and retrofit experience increased customer confidence to modify this particular unit. Feedback from the customer confirmed these impressions. The customer said that the boiler now performs far better than before the retrofit. While the emissions were lowered and the bark firing capacity increased, the customer found other economic and operational benefits to justify the retrofit. In particular, the boiler can handle more wet bark without support fuel - an additional savings. Overall, the customer said the complete retrofit project was very satisfactory.

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The Implication of CFB Technology for Repowering
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Abstract

One of main priorities of the energy strategy of Russia is to develop new economically efficient and environmentally friendly technologies. At the moment more than 100 old pulverized coal boiler with steam capacity of 170-240 t/h need to be reconstructed. Modern requirements on pollutions and possibility of low-grade coal firing make more attractive the usage of CFB technology.

This paper presents some results of an economic comparison and estimations of the power range vs typical Russian fuel quality. We compared different CFB technology modification. As a results it was demonstrated that it would be perspective to use CFB boiler with simple impact ash collectors. Some technical data of boiler design for Nesvetay thermal power plant (TPP) and Cherepetskay TPP are given. The prediction of CFB boiler operation parameters is based on CFB pilot data and results of the mathematical analysis.

Introduction

The majority of coals for power plants in Russia are low-grade products, the coals are of various compositions and have different properties. In 1997 more than 10^8 tons of coal were burned in the thermal power stations in Russia. They had the following mean parameters: an ash content of 27,9%, a moisture content of 19,4%, a sulfur content of 0,87% and low heat value of 16,49 MJ/kg.

One of the most urgent tasks for Russian coal-firing TPP is upgrading with increasing of coal utilization and reducing air pollution. VTI as a leader institute of Russian Joint Stock Company "EES-Russia" carries out the conceptual design of the boiler retrofitting. About 140 boiler with steam capacity near 200 t/h (pressure 10-14 MPa, temperature 510-540⁰C) were start up in 1950-1960 for utilization different solid fuels. The poor condition of many aged coal fired boilers makes their rehabilitation, including installation of pollution control equipment, economically untenable. These boilers have to be replaced. At the nearest time a retrofit or upgrading of some boilers for unit 200 and 300 MWe should also be done.

The additional of new coal-based generation capacity will be done mainly through repowering of the existing power plants. At that it is necessary to take into account that limited financial possibilities dictate to arrange modern requirements on pollution Glebov (1966) is an additional impulse for implication of new ecologically friendly technologies.

CFB technology is more attractive for repowering existing low-grade coalfiring TPP due to the following reasons:

- CFB boilers have a proven ability to efficient firing of low-grade fuels, including those with high ash, high moisture, high sulfur contents, low ash softing temperature.
- CFB technology has potential for utilization of the coal wastes without using of supplemental fuel within a wide load range.
- CFB boilers provide SO₂ and NO_x emission control meeting modern pollution requirements without using of the back and scrubbing systems.

An Economic comparison CFB pulverized (PC) coal boiler

The cost difference between CFB and PC boilers depends on several variables, including boiler size, fuel and sorbent quality and their cost, special domestic pollution requirements, which define capital and operating cost.

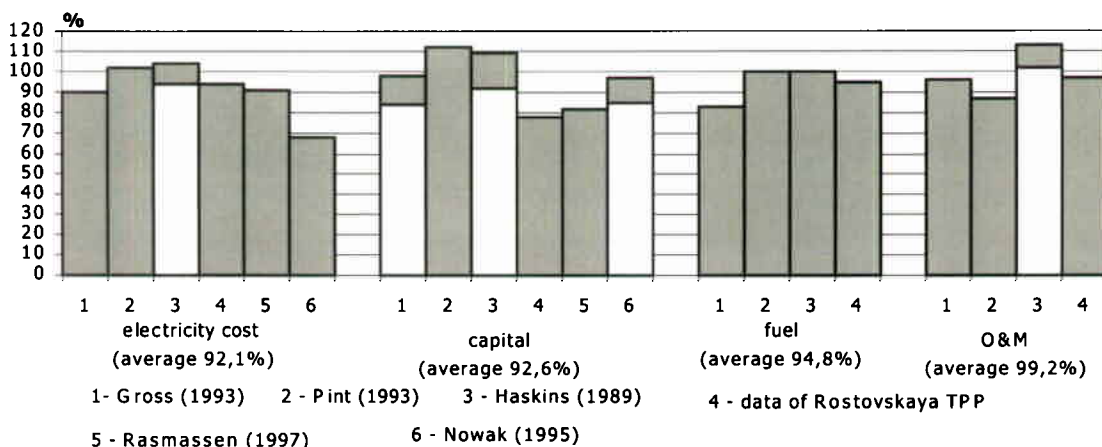


Fig 1. The comparison of specific cost of electricity for PC boiler with wet scrubber (100 %) and CFB boiler (units 150-200 MW)

The economic comparisons of CFB and PC boiler for units 15-200 MWt suggested that CFB boiler (fig 1) was the evaluated economic choice over PC boiler. CFB boilers are preferable for poor coal, including different to burn fuels and high sulfur coals which would require a wet flue gas desulfurization . At that capital cost of CFB boiler less than capital cost of PC boiler on 10% and operating cost is equal for both boilers. Our comparison of CFB and PC Boilers for Rostovskaya TPP demonstrated that CFB boiler for anthracite culm was the preferable choice over PC boiler (table 1).

Table 1

Specification	PC boiler with NO _x ,SO ₂ removal equipment	CFB Boiler
Emission		
NO _x , mg/m ³	240	200
SO ₂ , mg/m ³	400	300
Boiler efficiency, %	85,6	88,97
Capital cost, Mln rub. (1991)	3458,3	2699,7
Operating cost		
Auxiliary power, %	10,43	11,96
Fuel, Mln rub (1991)	5080,28	4852,08
Sorbent, Mln rub (1991)	a825,92	2752,47
Auxiliary fuel, Mln rub (1991)	332,71	227,94
The rate of unit fuel for 1 kW·h, g/kW·h	366,6	356,0
Capital cost evaluation for 1kWt, rub/ kWt	1351	1055
Total evaluation cost, rub/ kWt	112,5	100

There are many kinds of fuel in Russia which conform to the above conditions: some waste products, anthracite culm (low calorific value Q=17,2 MJ/kg, humidity W^r=10%, ash content A^d=36%, volatile yield V^d=4%, sulfur content S^d=1,4%) which mines in the Rostov region, high ash

and high sulfur coals (Near Moscow brown coal ($Q=8,4$ MJ/kg, $W^r=31\%$, $A^d=49\%$, $S^d=3,4\%$) and Pechorsky hard coal - ($Q=17,4$ MJ/kg, $W^r=11\%$, $A^d=35\%$, $S^d=3,2\%$), coal with low ash softing temperature. CFB is preferable for units, which utilize many kinds of fuels (Far East).

It should be noted, that capital cost for repowering of existing TPP with CFB boiler is 2,5 time less than new power plant construction. Specific capital cost of repowering with CFB boiler was estimated as 400-600 doll/kW. For example capital cost for repowering of units 150 MW (1 turbine, 2 boiler whis steam capacity 250 t/h) is about 500 doll/kW and the cost of electricity is about 0,045 doll/KW-h.

A comparison of different CFB technology modifications.

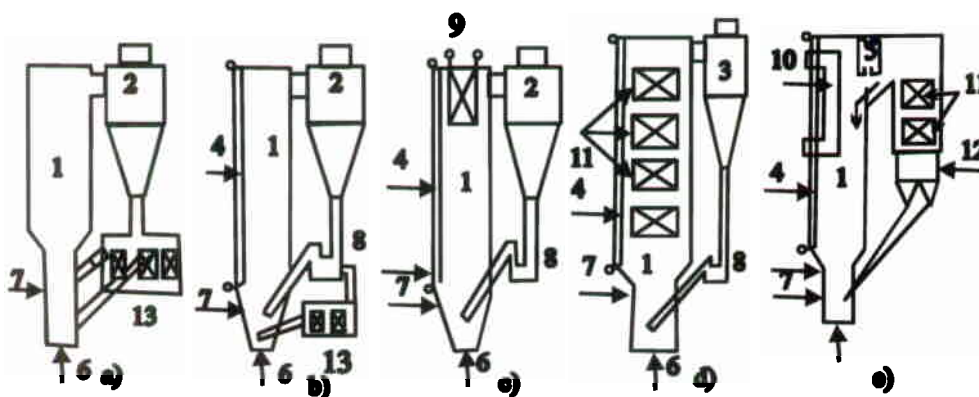


Fig.2 CFB technology's modification

1-furnace; 2 - "hot" cyclone; 3 - "cold" cyclone; 4- furnace walls; 5 - U-beam collectors; 6- primary air; 7 - secondary air; 8 - pneumatic valve; 9 - superheater in furnace; 10- wings superheater; 11- economizer; 12 - multicyclone; 13- ash heat exchanger.

Presented different types of CFB technologies have some distinctive peculiarities: heat rate of the furnace, solid separation design, start-up behavior, and temperature and load control. It is impossible to choose the best CFB technology without taking into consideration particular terms. Each of them is being evolved for actual conditions. The method of an expert estimation is used for such comparison. More than 10 different terms, including suitability of drain and flue ash for usage, are used for expert estimation Stork (1993). Three different types of CFB boilers were analyzed by Gierse (1990). Some data for boiler reliability comparison between U-beam vs. hot cyclone boilers are shown by Kavidass (1994).

A CFB boiler with hot cyclones and particularly with ash heat exchangers has a longitudinal start-up and requires more space for installation. However, these boilers have more flexible control of temperature and load as well as pollution. It should be noted that large capacity CFB boilers have been built with hot cyclones and ash heat exchangers.

We carried out the estimation of minimum sizes of two boilers with steam capacity 230 t/h for anthracite culm utilization (fig.3). Both of them have the height above existing boiler house height. The boiler with U-beam collectors is more compact and it may be installed in existing boiler house area. On our opinion CFB technology with compact ash

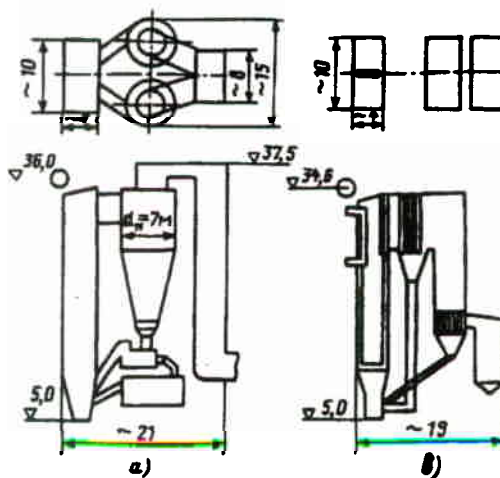


Fig.3 . Minimum sizes of the boilers with heat changers (a) and U-beam collectors (b).

collectors is more convenient for TPP upgrading equipped with 170-230 t/h boilers. For the large units which operated in wide range load CFB technology with ash heat exchangers it is a good choice, in particular for difficult to burn fuels.

Russian elaborations of CFB boilers.

Ten years ago in the USSR two designs of boilers were prepared and their erection began. One of them is for anthracite culm burning (Kurakhovskaya TPP-Ukraine) and the other - for near Moscow brown coal (steam capacity 500 t/h). But both projects were stopped after disintegration of the USSR. In accordance with "Ecologically Sound Power Engineering" national program the project of the 300 MW unit Rostov power plant with CFB boiler was prepared. There are once-through two-furnace (2×500 t/h) boiler with 4 hot cyclones and ash heat exchangers.

At the moment the general design of CFB boiler for Nesvetay TPP is finished as demonstration - commercial project for retrofitting many Russian boilers with steam capacity 170-240 t/h. This boiler is designed along with concern "Kotloprominvest" which has the license of Babcock & Wilcox company (USA) and Russian boiler manufacturers "Belenergomash" (Belgorod) and Taganrog Boiler Plant.

This project is financed by JSC "EES-Russia". The preliminary design shows that the new boiler is set up in old boiler building area (18×27 m²) with the 8 m increase of the building height. The boiler will utilize 33 t/h anthracite culm with 89 % efficiency (burn out losses - less than 5%). Emission of NO_x and SO₂ will be less than 300 mg/m³ and 400 mg/m³ respectively.

Other project is being carried out for high steam parameter boiler (steam capacity 250 t/h, pressure 18 MPa, temperature 540/540) of Cherepetskay TPP (Near Moscow brown coal, Kusnetsky hard coal). The most difficult problems are arrangement, construction and reliability of auxiliary equipment, first of all coal and sorbent preparation and feeding.

The scientific validation of CFB boiler design.

Scientific verification of technical solutions adopted in CFB boiler design was carried out at small-scale test combustors (Institute of Energy Saving Problems, National Academy of Science, Ukraine, leadership-A.Y.Maistrenko and Kazakhstan Institute of Energetic, leadership - K.A. Suleimenov) and pilot unit with thermal capacity up to 5 MW. These units were used for systematic and complex investigations of combustion processes for various coals, NO_x and SO₂ emission, start-up, shut-down and dynamic regimes. Investigations of the hydrodynamics, heat and mass transfer, gas-dust-laden flow mixing) were carried out on cold model. The review of this investigation was made by Haskins (1989). Some results of performed investigations are given below.

The studies were focused on the problem of high efficiency combustion of difficult to burn fuels, such as anthracite culm (ash content 30 - 45%, sulfur content 1,5 - 2,5 % and very small volatile - 4 %) and Near - Moscow brown coal (ash content 35 - 50 %, humidity \cong 20 %, sulfur content 2 - 5 %) with minimal impact to the environment.

Numerous data of kinetic tests (leadership - A.Y. Maistrenko) were used for mathematical model of combustion processes. It was showed that decreasing ash recycle temperature leded to decreasing of the char reaction rate. Coal burn-out depends from the ratio between particle residence time and burn-out time. This dependence was estimated by special tests on pilot unit in Kazakhstan when AC was fired (fig.4). Further on this data were utilize for analysis of the performance of large-scale combustors.

Owing to the fact that main heat losses are caused by carry - over with size less than 50 mkm, high combustion efficiency could be achieved with due regard to fractional coal composition, make sure it is not reduced to very little fragments. At the same time for AC utilization it should be limited the maximum size (3 - 6 mm, it depends from combustion technology modification).

Quantity of NO_x is determined by the choice of bed temperature (fig. 5,a) and air regimes (excess air fig. 5,b and share of primary air, fig. 5,c). It is shown that fuels which have very large (Near-Moscow brown coal) and very little (AC) volatile meter gives greatly NO_x formation. This phenomena was mentioned by Suzuki (1990). Molar ratio Ca/S (fig. 5,d) has considerable effect on NO_x level that has been already mentioned in a numbers of foreign publications.

Investigation of SO_2 removal have proved that in temperature interval 840 - 900 °C this value does not practically depends on furnace chamber temperature (fig. 6,a). More than 90 % sulphur fixation was obtained at ratios Ca/S above 2 (fig. 6,b).

When we started CFB boiler designing for Kurachovskay power plant, the task of automatic control appeared. In order to study CFB boilers as new objects of control it is necessary to know the dynamic properties of those units.

There are a lot of investigations Shang(1991), Bernardi (1990), Neidel (1987) which static and dynamic models of CFB circuit are described. However, only the main idea underlying the construction of model is usually presented. The input parameters of our model (for given design parameters and characteristics of the fuel) are the fuel and limestone consumption and the flowrate and temperatures of the primary and secondary air. The output parameters of model are the main factors of disperse flow in the furnace circuit such as temperature, oxygen and carbon contents, the amount of heat received and the losses from unburned carbon. It should be noted that the flowrate of solid recycle rate to the furnace is not always equal to the flowrate of solids coughing in the ash collectors under dynamic conditions. And we take into account this phenomena.

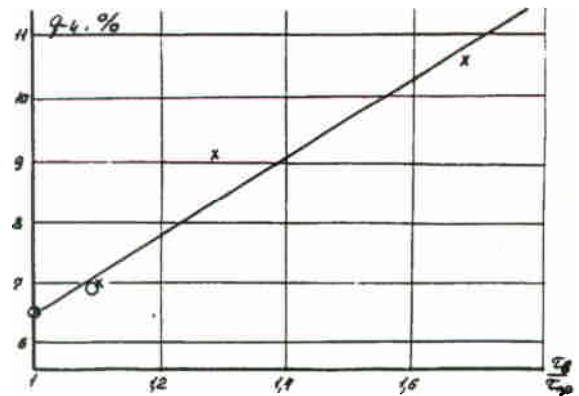


Fig. 4. Coal burn-out vs ratio between burn-out time and residence time (AC).

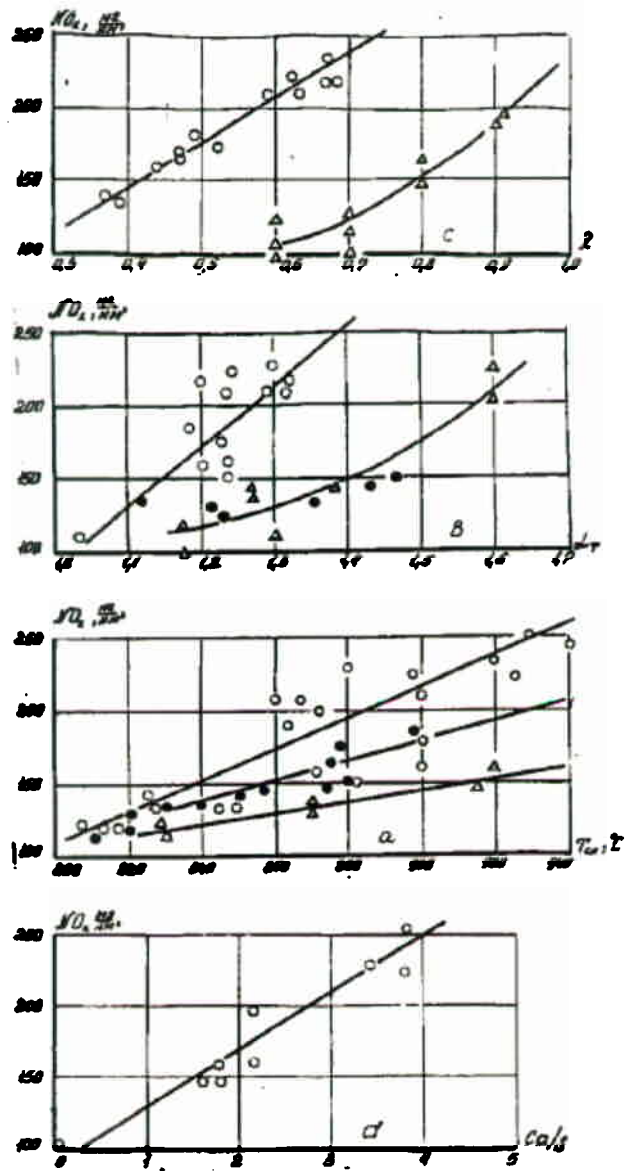
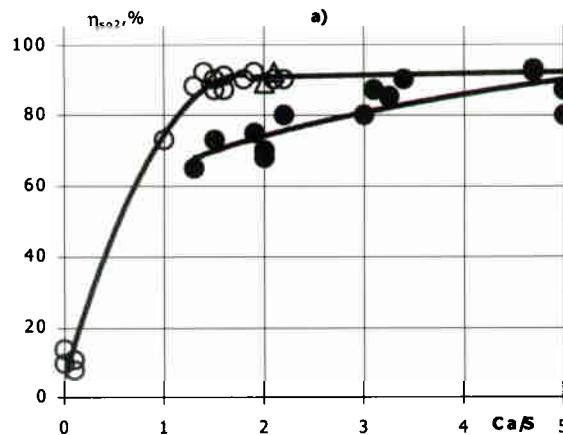


Fig.5 Relation between NO_x and bed temperature (a), excess air (b), primary air share(c), Ca/S molar ratio (d). (o - Anthracite culm(1); • - Near-Moscow brown coal(2)).

Detail description of the model is shown by Kadnikov (1994) were elaborated by dr. B. Kadnikov. It was the simple one-dimensional dynamic model, but the general idea of our investigation was to obtain experimental data from coal firing units in order to check that the model was corrected. General tests were carried out on KazNIIenergetika small size unit (cross section 0,3 m², height - 3,2 m). Other tests were made on pilot unit whis thermal capacity 5 MW. Data on the performance of these units under static and dynamic conditions were obtained by burning AC.



In the tests a certain input variable was changed by step (in test 1, the primary air flow was reduced by 10%; in test 2, the fuel consumption rate was reduced by 20%) or a group of input variable were changed (in test 3, the load of the unit was reduced from 90 to 70 %, the fuel consumption rate was reduced, and the primary and secondary air was reduced proportionally to maintain a given excess air level at the outlet from the furnace.

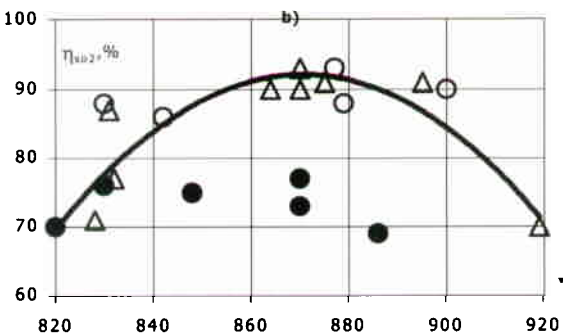


fig.6 Relation between sulfur capture efficiency and Ca/S molar ratio (a) and bed temperature (b), coal kinds -fig.5

A comparison of calculations and test results concerning the dynamics of the CFB installation is presented in fig's 7 and 8. Curves are presented of the relative time-varying temperatures in the lower part of the furnace (fig. 7a) and in the return line (fig. 7b) for all types of disturbances described above. Calculations and test results of the temperature in the CFB circuit agree satisfactory. When the temperature in the dense bed of the model was calculated, we also calculated time variations of other important parameters characterizing the performance of the installation; specifically, the carbon content in the dense bed (fig. 8a), the consumption of the material that circulated in the return line of the unit (fig. 8b) and others. These calculations also agreed satisfactory with the test results.

Obtained data permitted to define more precisely domestic calculation method for boiler designing.

The next step in CFB boilers design is the natural progression to supercritical pressure steam cycles and boiler capacities matching the PC boiler of 350 MWe or higher as shows Wietzke (1996). SU had large experience in design and operation of higher supercritical boilers. VTI (Godik,1991) investigation shows that CFB technology is a good choice for higher supercritical parameters: 3 MPa, 600/560/560 °C . Due to a relatively low level of heat flux in the furnace of CFB boiler, there is no further need for in-service proving of all-welded waterwalls made from EI-756 steel. The calculations showed that the requirements for long-time strength with safety margin were already met by the tested finned waterwalls made from 12Cr1MoV steel, D=32 mm, wall thickness 6 mm. When intermediate stages of the superheater and reheater are located in external heat exchangers which have a high level of heat flux, the tubes can be made from the widely-used 12 Cr18Ni12Ti steel or EI-756 chrome steel (1 Cr11W2MoV) which is now being tested. VTI investigation showed that thermal efficiency of power-generating unit with CFB boiler on higher parameters could be similar to supercritical unit of standard parameters and combined-cycle plant with in-cycle gasification of solid fuel.

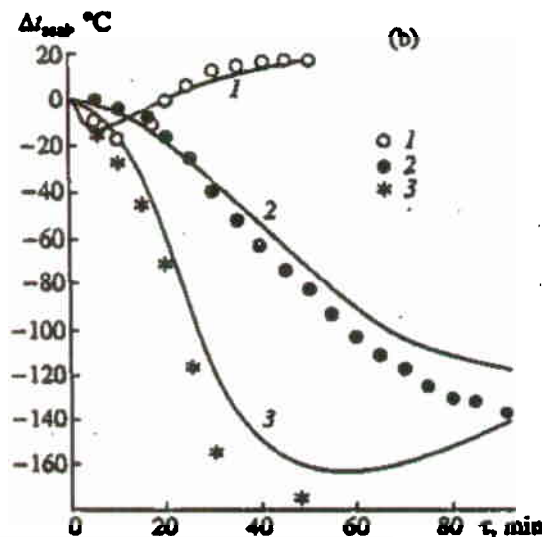
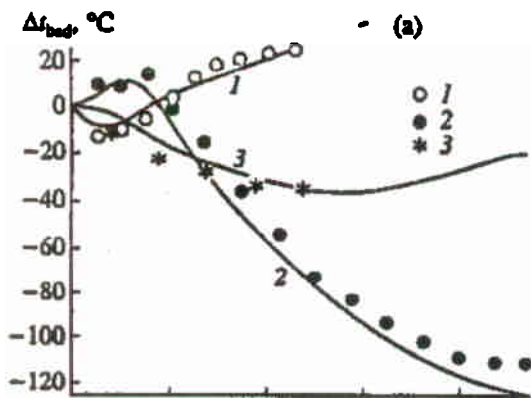


Fig. 7. Comparison of calculations and experimental results of transients. (a) temperature in the turbulent bed of the furnace; (b) temperature in the return line; (1 - 3) tests 1 - 3.

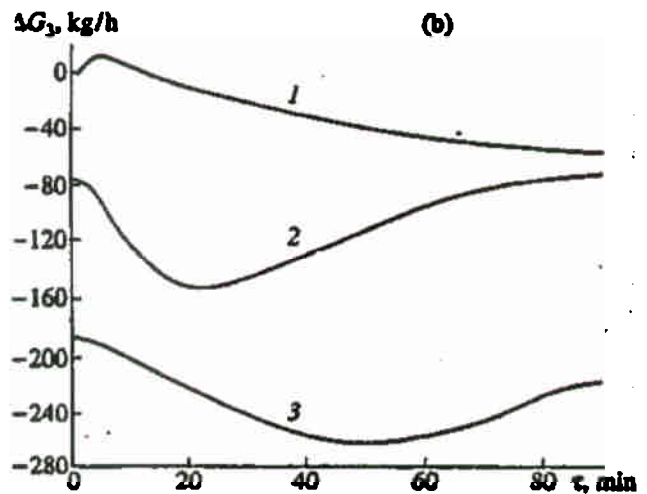
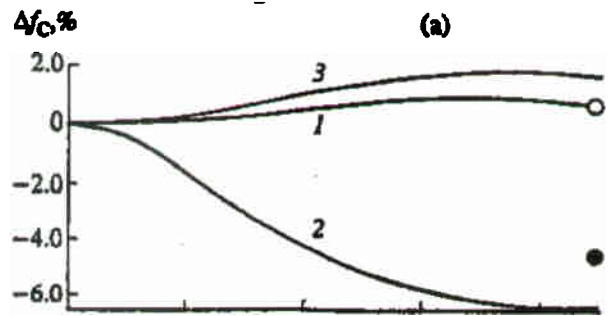


Fig. 8. Calculated curves of transients in the CFB circuit: (a) carbon content in the bed; (b) flowrate of the material in the return line.

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Fluidized Bed Combustion

Fluidized bed combustion systems use a heated bed of sand-like material suspended (fluidized) within a rising column of air to burn many types and classes of fuel. This technique results in a vast improvement in combustion efficiency of high moisture content fuels, and is adaptable to a variety of "waste type fuels. The scrubbing action of the bed material on the fuel particle enhances the combustion process by stripping away the carbon dioxide and char layers that normally form around the fuel particle. This allows oxygen to reach the combustible material much more readily and increases the rate and efficiency of the combustion process.



Bed Recycle System

The key to EPI's dominance of the difficult waste fuel combustion market is our patented bed recycle system. EPI is the only company that offers uniform bed drawdown, integrated air cooling and automatic cleaning and reinjection of the bed material. This innovative feature enables EPI systems to operate on fuels with significant quantities of 4-inch minus noncombustible tramp material (contaminants such as rocks, metal, etc.). In grate style systems, tramp materials and ash slag can cause significant problems requiring a shutdown to correct. In other fluidized bed systems, tramp materials can build to the point that fluidization is no longer possible allowing clinkers to form. In these systems, a shutdown is usually also required to clean out the accumulation.

Complete and Efficient Combustion.



The turbulence in the combustor vapor space combined with the tumultuous scouring effect and thermal inertia of the bed material provide for complete, controlled and uniform combustion. These factors are key to maximizing the thermal efficiency, minimizing char, and controlling emissions. The high efficiency of a fluid bed combustor makes it particularly well suited to problem fuels with low BTU value and high moisture characteristics. EPI's systems have consistently achieved high combustion efficiencies. In typical units, the carbon burnout percentages within the combustor are well in excess of 99 percent.

Waste Fuel Diversity

EPI systems have operated on fuels as diverse as agricultural waste, municipal solid waste, wood wastes, industrial and municipal sludges, plastic, tires and coal. Fluidized bed systems are also capable of efficiently combusting fuels of varying consistency. EPI units have demonstrated the ability to handle a variety of wastes within a single combustor. EPI's San Joaquin Valley Energy Project units have logged operating time over 68 varieties of agricultural and urban wood waste. EPI's patented bed cleaning system, which removes large non-combustible material from the bottom of the bed, allows EPI units to burn otherwise problematic fuels with a minimal amount of processing.

Low Emissions

Emissions from a fluidized bed unit are inherently lower than conventional technologies for the following reasons:

- ✦ Low combustion temperatures and low excess air within the bed reduces the formation of certain emissions such as NO_x .
- ✦ High combustion efficiency results in flue gases that contain low amounts of CO.
- ✦ Emissions such as SO_x and NO_x may be abated within the fluidized bed system by injecting limestone into the bed and ammonia into the vapor space.

These features of fluidized bed combustion, combined with EPI's vast experience with a variety of fuels have allowed EPI units to comply with some of the most stringent air quality regulations in the country, including six operating plants in California. EPI units have consistently been accepted as the Best Available Control Technology "BACT" by environmental regulatory agencies.

Favorable Ash Properties

The high combustion efficiency of a fluid bed results in a reduced amount of inorganic material as fine ash. The remaining larger material consists mainly of non-combustibles, such as rocks, and wire brought in with the fuel, and coarse sand-like neutral particles. Low combustion temperatures in the fluidized bed minimize the formation of toxic materials that might go into the ash. Ash samples from EPI systems have consistently tested nontoxic, and in many instances the ash is being sold as input for other products such as cement.

Operating Flexibility

EPI's fluidized bed systems have demonstrated the ability to operate under a wide range of load conditions. The thermal "flywheel" effect of the bed material allows swings in moisture and heating content of the fuel to be absorbed by the system without negative impact. Conversely, the low fuel inventory present in the unit makes it very responsive to varying loads. The fluidized bed also maintains efficiency during system turn-down. The operating flexibility demonstrated by existing EPI units has proven quite valuable for some of EPI's customers allowing them to take advantage of utility incentive programs for generation that follows electric demand.

Low Operating Costs

The lack of moving parts in a fluid bed reduces maintenance costs and down time. EPI units have achieved operating availabilities above 98% and have kept operating costs relatively low given the difficult fuels they are burning.

Environmentally Sound Energy Production from Waste

Fluidized bed combustion is an environmentally favorable, proven technology for disposal of solid wastes and generation of energy. The combination of EPI's vast experience in developing solutions for a wide variety of applications, with the favorable characteristics of

fluidized bed combustion make EPI the leader in providing environmentally sound waste disposal solutions.

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DOE Selects Six Cellulosic Ethanol Plants for Up to \$385 Million in Federal Funding

The U.S. Department of Energy today announced that it has selected six cellulosic ethanol plants for up to \$385 million in federal funding.

WASHINGTON, DC

The U.S. Department of Energy today announced that it has selected six cellulosic ethanol plants for up to \$385 million in federal funding. The plants are: Abengoa Bioenergy Biomass of Kansas, LLC of Chesterfield, Missouri, up to \$76 million; Abengoa Bioenergy Biomass of Louisiana, LLC of Lake Charles, Louisiana, up to \$76 million; Abengoa Bioenergy Biomass of North Carolina, LLC of Raleigh, North Carolina, up to \$76 million; Abengoa Bioenergy Biomass of South Carolina, LLC of Columbia, South Carolina, up to \$76 million; Abengoa Bioenergy Biomass of Texas, LLC of Houston, Texas, up to \$76 million; and Abengoa Bioenergy Biomass of Virginia, LLC of Charlottesville, Virginia, up to \$76 million.

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plant will produce 11.4 million gallons of ethanol annually and enough energy to power the facility, with any excess energy being used to power the adjacent corn dry grind mill. The plant will use 700 tons per day of corn stover, wheat straw, milo stubble, switchgrass, and other feedstocks.

Abengoa Bioenergy Biomass investors/participants include: Abengoa Bioenergy R&D, Inc.; Abengoa Engineering and Construction, LLC; Antares Corp.; and Taylor Engineering.

- **ALICO, Inc. of LaBelle, Florida, up to \$33 million.**

The proposed plant will be in LaBelle (Hendry County), Florida. The plant will produce 13.9 million gallons of ethanol a year and 6,255 kilowatts of electric power, as well as 8.8 tons of hydrogen and 50 tons of ammonia per day. For feedstock, the plant will use 770 tons per day of yard, wood, and vegetative wastes and eventually energycane.

ALICO, Inc. investors/participants include: Bioengineering Resources, Inc. of Fayetteville, Arkansas; Washington Group International of Boise, Idaho; GeoSyntec Consultants of Boca Raton, Florida; BG Katz Companies/JAKS, LLC of Parkland, Florida; and Emmaus Foundation, Inc.

- **BlueFire Ethanol, Inc. of Irvine, California, up to \$40 million.**

The proposed plant will be in Southern California. The plant will be sited on an existing landfill and produce about 19 million gallons of ethanol a year. As feedstock, the plant would use 700 tons per day of sorted green waste and wood waste from landfills.

BlueFire Ethanol, Inc. investors/participants include: Waste Management, Inc.; JGC Corporation; MECS Inc.; NAES; and PetroDiamond.

- **Broin Companies of Sioux Falls, South Dakota, up to \$80 million.**

The plant is in Emmetsburg (Palo Alto County), Iowa, and after expansion, it will produce 125 million gallons of ethanol per year, of which roughly 25percent will be cellulosic ethanol. For feedstock in the production of cellulosic ethanol, the plant expects to use 842 tons per day of corn fiber, cobs, and stalks.

Broin Companies participants include: E. I. du Pont de Nemours and Company; Novozymes North America, Inc.; and DOE's National Renewable Energy Laboratory.

- **Iogen Biorefinery Partners, LLC, of Arlington, Virginia, up to \$80 million.**

The proposed plant will be built in Shelley, Idaho, near Idaho Falls, and will produce 18 million gallons of ethanol annually. The plant will use 700 tons per day of agricultural residues including wheat straw, barley straw, corn stover, switchgrass, and rice straw as feedstocks.

Iogen Biorefinery Partners, LLC investors/partners include: Iogen Energy Corporation; Iogen Corporation; Goldman Sachs; and The Royal Dutch/Shell Group.

- **Range Fuels (formerly Kergy Inc.) of Broomfield, Colorado, up to \$76 million.**

The proposed plant will be constructed in Soperton (Treutlen County), Georgia. The plant will produce about 40 million gallons of ethanol per year and 9 million gallons per year of methanol. As feedstock, the plant will use 1,200 tons per day of wood residues and wood based energy crops.

Range Fuels investors/participants include: Merrick and Company; PRAJ Industries Ltd.; Western Research Institute; Georgia Forestry Commission; Yeomans Wood and Timber; Truetlen County Development Authority; BioConversion Technology; Khosla Ventures; CH2MHill; Gillis Ag and Timber.

Cellulosic ethanol is an alternative fuel made from a wide variety of non-food plant materials (or feedstocks), including agricultural wastes such as corn stover and cereal straws, industrial plant waste like saw dust and paper pulp, and energy crops grown specifically for fuel production like switchgrass. By using a variety of regional feedstocks for refining cellulosic ethanol, the fuel can be produced in nearly every region of the country. Though it requires a more complex refining process, cellulosic ethanol contains more net energy and results in lower greenhouse emissions than traditional corn-based ethanol. E-85, an ethanol-fuel blend that is 85-percent ethanol, is already available in more than 1,000 fueling stations nationwide and can power millions of flexible fuel vehicles already on the roads.

For more information on President's Bush's Twenty in Ten Initiative, visit: <http://www.whitehouse.gov/stateoftheunion/2007/initiatives/energy.html>

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