Sustainable Remediation of Large-Scale Contaminated Sites of the Oil Industry

Experiences and Conclusions of the Remediation of the Acid Tar Deposits at Chemnitz

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Sulfuric acid-containing wastes, so called acid tars, belong to the most dangerous residues. They accrue from the refining process of waste oil using concentrated sulfuric acid. This paper shows an example of a successful remediation of the acid tar lagoons in the near of Chemnitz, where all major criteria of a sustainable remediation were taken into account after weighing the costs and benefits. This example points out a conclusion for comparable projects elsewhere.

Large scale contaminated sites of the oil industry have been an immense danger potential for human beings and environment especially in intensely populated areas and also often block the structural development of the whole region. The execution of remediation concepts very often fails due to the lack of remediation technologies and disposal routes for residues that have to be removed.

Since 1991 Baufeld-Mineralölraffinerie GmbH is responsible for the remediation of the ecologic contaminated sites of the former Motimol company at Chemnitz, a district of Klaffenbach, in accordance to § 4 of Federal Soil Protection Act (BBodSchG). The remediation comprises the production area of the refinery, which was in operation from 1898 and therefore contaminated with HC and BTEX, as well as the remediation of the former deposits at Mittelbach and Neukirchen, both near Chemnitz, consisting of five acid tar lagoons and a landfill site containing a mixture of solid material. At these sites, former sand and clay mines, liquid and pasty hydrocarbon mixtures with high sulfuric acid shares (highly aggressive pollution potential with an pH-value of 0–1) resulting from the waste oil refining has been disposed from the 1940s until the 1990s of last century.

Ground and surface water, human beings and animals were jeopardized. Additionally there was massive odour nuisance of residents. A fluid layer on top of the lagoon surface containing heavy contaminated aggressive oil-water-sulfuric acid-emulsion resulting from water influx and rainfall caused a permanent danger of overtopping of the lagoons or breaking dams because of their partial instability.

Figure 1: Acid Tar Lagoon Mittelbach before remediation

Frame of Activities and Project Management

Approximately 100 Mio € of public money have been funded since 1996 by the Free State of Saxony within the frame of the financial legacy exemption in accordance with the environmental framework law (UmwRG).

The major goals and tasks for the solution of this project and the related remediation strategies were determined as follows:

- To remediate the site sustainably and to avoid a postponing of the problem to future generations, even in the case of a secured deposition.
- To take into account the legal and technical requirements, which are based on environmental goals and restrictions by soil protection, law at any time.
- To ensure the instantaneous and sustainable financing by the public budgets.
- To consequently execute a best controlled project on this financial basis.

A possibility of comparison of such national and international remediation did not exist while planning and executing the Chemnitz project.

Each interruption of the remediation would have caused far-reaching consequences up to increasing danger by pollution, imminent public problems and extraordinary additional costs due to delays.

All stakeholders, engineering firms, financing and technical authorities and Baufeld as contractor as well as site owner agreed upon the consequent avoidance of those or similar risks. Therefore, the provision of sufficient legal and planning security had to be established.

For this purpose, all procedures and agreements for investigation as well as for planning, operational preparation and execution of the remediation and the tracking of results had to be clearly structured. Based on this structure the optimization of all necessary and cross-linked processes of the various works could be reached.

However, this optimization was only possible because all reconcilements were compulsory for stakeholders. Reconcilements comprised technical and economical as well as legal and administrational issues. As the best eligible instrument, so-called remediation financing contracts were developed and implemented for a successful project execution.

In the course of the remediation process uncertainties concerning real volumes of acid tar and contaminated soil became obvious. During the phase of investigation of the site, it was not possible to evaluate all details of the complex geological conditions of the ground and dams of the lagoons since a documentation of the former deposits was not available. At least due to these insecurities, the project had to face the problem of additional volumes.

Those uncertainties of volumes led to extraordinary additional coordination and reconcilements. To avoid technical and financial risks it was necessary to adapt technologies and procedures, which called for decisions by the authorities, without questioning feasibility and benefit of the whole project.

Due to the close cooperation of the stakeholders and by an efficient project management by BAUFELD-UMWELT-ENGINEERING GmbH, working for the contractor, and by the project controller ARGE AFC, working for the Free State of Saxony, including all necessary survey and engineering works, it was possible to minimize those risks, despite the size and complexity of the entire project.

In the course of the project, it happened that determined and agreed activities had to be changed due to the appraisals from surveyors respectively planning bureaus. Thus, quick decisions could be taken, technically as well as financially. It was made sure that those changes were included into the contracts and construction activity-plans. Cost-measurement-work-schedules were extended. Occurring additional volumes were contracted on a comparable procedure.

As major prerequisites, there were project reviews on a regular basis, weekly construction meetings and a system of measure-, Baufeld´s project management and client´s project controller consequently applied cost- and schedule controlling in order to reach remediation and budget goals for the subprojects phase by phase.

Overview of the Remediation Projects

Since 1991 Baufeld has been executing and tracking step by step in a close dialogue with the authorities for soil protection, exemption and funding, based on measure- time and cost plan, concerning areas and objects, the following measures:

- Necessary investigations and a risk assessment.
- Development of technologies for treatment of the materials and usage of the residues.
- Evaluation of remediation variants based on technical examination, cost-benefit analysis and risk consideration by comparing the variants.
- Development of remediation plans following the soil protection law and ensured the binding declaration of the authorities.
- Remediation financing contracts for each subproject.
- Preparation of remediation measures, organization of the related tender processes and putting measures into practice.

On this basis, an optimization of the remediation measures of each subproject could be achieved. Experiences made in a subproject were transferred to the next following subproject, whereas the technologies developed for treatment of acid tar by Baufeld was taken as a major factor of the whole project.

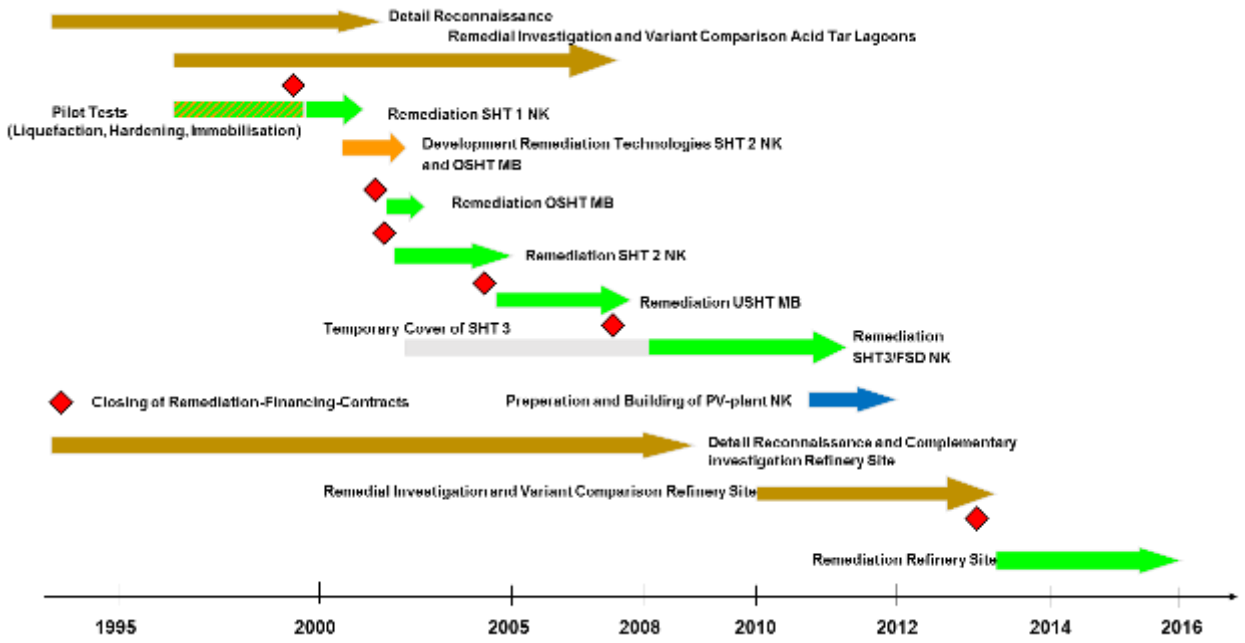

Figure 2: Time schedule of Baufeld's acid tar remediation

Within the very complex project system, consisting of six remediation objects at two locations, more than 80 special actions for investigation, 70 separate measures for remediation, planning and preparation and more than 100 main activities for execution and tracking as well as post care and last not least three very comprehended permission processes with regard to the Federal Emission Protection Law were taken and conducted.

In the course of 15 years, a total amount of 185,000 tons of acid tar had been excavated, treated and the resulting 360,000 tons of secondary fuel nearly entirely used in the co burning process at a lignite-fired power plant (mainly Schwarze Pumpe, operated by Vattenfall) for energy recovery.

Table 1: Scheme of remediation projects with cubature and schedules of depositing and remediation

Remediation projects		**Acid tar (waste) in t**	**Schedule of depositing**	**Remediation schedule**
Neukirchen	Acid tar lagoon 1 (SHT 1)	15.000	1990–1991	1997–2000
	Acid tar lagoon 2 (SHT 2)	78.000	1976–1989	2001–2005
	Acid tar lagoon 3 (SHT 3)	31.000	1953–1976	2008–2012
	Solid waste land fill site (FSD)	(225.000)	1945–1990	2008–2012
Mittelbach	Upper acid tar lagoon (OSHT)	2.000	1943–1953	2002–2003
	Lower acid tar lagoon (USHT)	62.000	1950–1980	2005–2008

Furthermore, approximately 100,000 m³ of contaminated oil-water-sulfuric acid-emulsion had to be treated and disposed. For the treatment, Baufeld used its own technical equipment and technology.

The remediation of the acid tar lagoons were successfully finished in 2012. As a follow up usage of the area in Neukirchen a photovoltaic plant with a performance of 2.7 MW_p was build and put into operation.

A part of the remediation project is the remediation of the refinery site at Klaffenbach. Since 2013 soil remediation measures by means of soil exchange have been executing at specific determined contaminated locations up to 3 m below ground level with a total volume of 15,000 m³ of contaminated soil.

Construction costs and costs for disposal are optimized due to an in-situ pre-declaration of the contaminated soil. Because of the hydrological conditions of the site, a lowering of groundwater has been carried out during the remediation process together with the treatment of approximately 75,000 m³ of contaminated groundwater in an extra installed treatment plant using a specific technology.

By application of appropriate remediation and safeguarding measures, any further release of pollution from the contaminated locations could have been and will be avoided. The whole project will be finished successfully by the end of 2016.

Pollution and Risk Potential

The acid tar residues of Chemnitz are the reaction product of concentrated sulfuric acid with petroleum-derived hydrocarbons, additives, oxidation products and other contaminations caused by specific applications of used oil. Therefore, acid tars have a strong sulfuric aggressive character and a content of sulphur up to 15 % (table 2)

Table 2: Parameter of acid tar

Parameter	**Dimension**	**Values**
HC	Ma-%	7–25
S_{total}	Ma-%	8–15
Heating value	MJ/kg	14–22
Ash content	Ma-%	0,65–9,38
pH-value		0,08–1,5
Cl	Ma-%	0,01–0,03
PAH	mg/kg	50–200
CHC	mg/kg	0,1– 0,8
BTEX	mg/kg	0,2–1,3
Zinc	mg/kg	225–3.100
Pb	mg/kg	35–687
Hg	mg/kg	< 1–4,2

Investigations and Tests

Beside the conventional investigation by means of a hydrologic geologic inventory control considering the topographic situation and the surroundings of the project area, a comprehensive analysis of the residues was crucial for the success of the remediation. The material analysis required an extensive sampling and testing of the acid tar, the contaminated water layer on top of the lagoon, the soil and the dams as well as the investigation of geological issues of the different acid tar lagoons.

Furthermore, tests with products derived from acid tar were carried out, in order to receive the optimal recipes for the treatment process of the acid tar. Variants of mixtures of different basic material qualities with suitable additives were tested to reach a largely homogeneous product quality.

A main reason for the tests was to suggest the application of the technology for the industrial scale usage by taking the results of the laboratory tests.

A major concern of the acid tar remediation process is the emission reaction of the acid tars, especially the sulphur dioxide emissions, which occur during excavation and treatment of the acid tar. Those emissions had to be minimized by additional specific measurements and technical emission reduction measures.

Further ongoing investigations regarding dams of the former deposits had been taken parallel to the excavation of the acid tars in the course of the remediation, in order to exploit and estimate major risks of additional volumes and as a follow up the risk of additionally necessary performance and financing prematurely. Monthly surface measurements of the reached level of the lagoon had been taken and compared with the level of the lagoon at the beginning of the remediation. Thus, a plausibility of the excavated volumes could be found.

Remediation Technologies with Preference of Energy Recovery

The key element of the remediation of all acid tar lagoons was the largest possible excavation, treatment and energy recovery of acid tars due to their extraordinary dangerous relevance. This sustainable remediation strategy, targeting for the benefit of future generations, was convincing as the most economic one of each of the sub projects.

This strategy of an entire excavation and the energy recovery has turned out as feasible and safely executable in a long lasting process, since problems have occurred 10 years ago, when changes of the law concerning landfills did not allow the disposal of such hazardous waste any longer.

It has to be emphasized that the applied technologies for excavation, treatment and product usage required a high level of innovation and flexibility, because of the aggressiveness of the acid tar and the varying qualities of the material. Baufeld developed technologies, which fulfilled these requirements. Special issues in this context are as follows:

- Abrasion resistance of the excavation and treatment techniques regarding the extraordinary acid and corrosively effective residues as well as taking the existing contraries into account.
- A comprehensive reduction of emissions during the course of the excavation and treatment of the acid tar, applying suitable technologies and gas cleaning systems, especially concerning sulphur dioxide and hydrocarbons.
- Process techniques flexibly manageable with recipes adaptable to the chemical-physical composition of the residues and taking into account the quality criteria requirements of the power plants concerning energy recovery of the acid tar derived products.
- Extra developed transport containers and a logistic concept for transport of the pure acid tars to an on-site and off-site treatment unit respectively for transport of the treated material to a power plant for energy recovery.
- Production lines for treatment of oil-water-sulfuric acid-emulsion were held available.

Comprehensive emission protection and controlling measures were implemented in order to avoid danger for residents in the direct neighbourhood.

The developed technology was exemplary for a number of similar projects in Europe.

The 4 largest lagoons at Neukirchen and Mittelbach, with a volume between 15,000 and 78,000 tons, a surface between 3,000 and 8,000 m² and a depth of up to 9 m, were entirely excavated. The acid tars were treated on-site or off-site and afterwards the secondary fuels were used for energy recovery by co-burning. It was crucial to develop the plants in detail targeting for a permanent treatment throughput of 3,000 tons per month during the whole remediation period.

Regardless of the above-mentioned approach, remediation goals, characteristics of the referring locations and cost benefit goals were taken into account. This led to the solution to leave remaining neutralized and stable acid tar and mineral contaminated material and soil at the sites.

Safeguarding Measures Targeting for Cost Optimization

Due to large volumes of acid tar and mineral contaminated material especially the lower acid tar lagoon at Mittelbach and the acid tar lagoon 3 at Neukirchen were a great challenge for the remediation concept. The goal of remediation concepts for these lagoons was to embed these materials into the lagoon, above the groundwater level, in a protecting way. The former sand surface mine and therefore the permanent precipitation caused a high contamination of the dams and the ground of the lagoon at Mittelbach.

Due to the hydrogeological and topographic situation of the lagoon, it was possible to allow that these materials could remain entirely in that part of the lagoon that was located above the groundwater level.

The equal materials of the other part of the lagoon, which partly were located where groundwater was impacted by contaminations, could be shifted to that part of the lagoon that was excavated first. This was carried out while acid tar was excavated systematically and the dams were removed concurrently.

A suitable drainage and sealing system was installed and ensured, as a long lasting solution, so the penetration of water and thus the elution of harmful substances were inhibited.

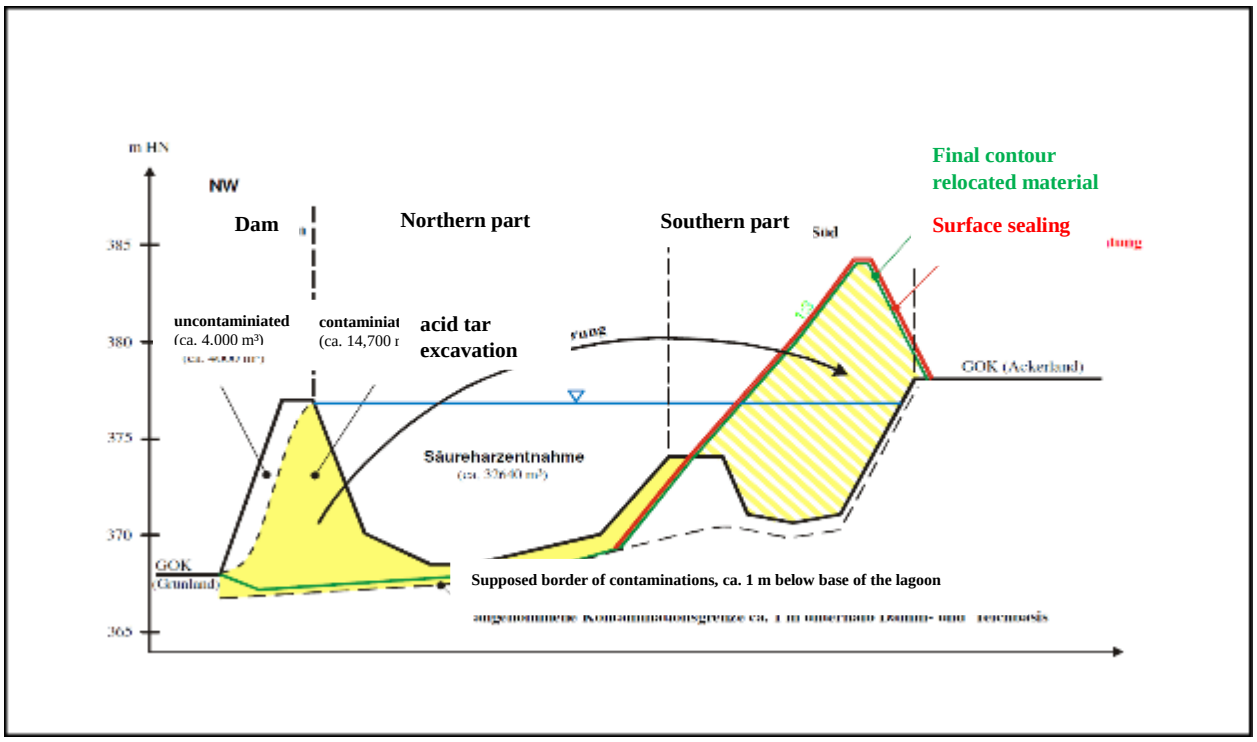

Figure 3: Scheme of relocating contaminated materials of the Lower acid tar lagoon at

Figure 4: Excavation of the different parts of the acid tar lagoon in Mittelbach

Another big challenge of the remediation planning was a complex situation at the acid tar lagoon 3, the last one and oldest acid tar lagoon in Neukirchen. This lagoon was covered from 2003 until the beginning of the excavation of the acid tar in 2009 intermediately with a foil system to avoid contaminations occurring by contacting of rainfall water with the acid tar of the lagoon.

During the 1970s and 1980s, it was tried by the owner of the deposit to bring a layer of construction material on top of the surface of the acid tar lagoon and to cover this layer with soil several times. This resulted in very instable banks and many contraries within the lagoon.

Figure 5: Excavation of acid tars at the lagoon 3 in Neukirchen with stabilisation of dams

Materials of the different layers were varying in their form and contents. Neither was the interface to the landfill clearly determined. Investigations therefore were focused especially on water flows and the danger of movement of fluid and pasty acid tars as well as on determination of volumes of materials.

The excavation of this lagoon was carried out by leaving the intermediate cover on parts of the lagoon as long as possible in order to minimize volume of contaminated water to be disposed.

The remediation goals were achieved by:

- Excavation and disposal of the unstable acid tar.
- Stabilization of the contaminated material of the dams, impurities and the lagoon ground, which was capable for removal and not capable for bearing, using lime and a special milling technique.
- Reassembly of the material, cohesive and compressed, layer by layer, up to a determined level, also under the view that a hydraulic decoupling of the contents of the lagoon from the area around could be reached.
- Profiling of the lagoon area in combination with the landfill area and developing of the final contour.

- A surface sealing of the former lagoon area coordinated to the contamination of the rest contents and a mineral cap in the area of the solid landfill site.

Already in 2002/2003 at the small lagoon in Mittelbach (upper acid tar lagoon) liquid and pasty acid tar material was stabilized off-site and then embedded as stable settlement product and then covered by a foil system. The crucial prerequisite was a safe system that ensured the avoidance of a mutual reaction of remaining residues with groundwater. This concept, including a complex housing using a tent during the remediation process, was preferred due to economic reasons.

Experiences compared to Foreign Projects

The experience of BAUFELD-UMWELT-ENGINEERING gathered from its own projects has been requested by a number of comparable remediation projects in foreign countries during the last years. An example is an acid tar project in the Baltic States, which is similar to the Chemnitz projects.

Baufeld contributed its experience of investigation, planning and execution in the context of the assessment of a feasibility study for the European Union in 2007 and later as expert for a local engineering office during the remediation from 2011 until 2015.

This project is co-funded by the European Union and therefore subjected to comparable stringent procedures of planning and execution. The project is characterised by 80,000 t of acid tar and acid tar contaminated soil, contaminated surface water and an extensive groundwater contaminated. It consists of two subprojects with an area of 25,000 m² and has been finished by the end of 2015.

The technical concept targeted for the highest possible on-site-treatment of the acid tar in order to produce a secondary fuel for co-burning and energetic utilization and included technologies that were developed and applied to the Chemnitz project. A cement kiln was chosen for co-burning, as it was able to take this material by means of approvals and technical aspects. Prior to the remediation, the operation was not tested. The treatment technology has to be adjusted.

Due to quality inconsistencies of acid tar during the works the application of the cement kiln was limited because utilization capacity did not reach planned amounts. Therefore, the co-burning had to be executed parallel on a power plant. The transport to Germany required an approval of international transport of the hazardous waste and a complex logistic.

In the course of the project different problems occurred due to insufficient tests and difficulties of the technical execution caused by varying acid tar qualities. These problems led to extensive delays, to a significant cost overrun and at the end to the interruption of the project. The contracts with the contractors were suspended. A new tender is actually in preparation.

The reasons for the problems are complex and were assessed by the involved authorities, the site supervision and an incorporated consulting organization of the European Union.

From the point of view of Baufeld a technological, organizational and financial inventory, including an analysis of occurred problems, are necessary for the continuation of the project. To this, an additional investigation – to eliminate knowledge gaps – and a revision of the remediation concept including a revision of the remediation aims have to be conducted prior to a new tender. Compared with the Chemnitz projects it can be shown, that a successful continuation and completion is only possible in the case that the aforementioned points are integrated into the new tender documents and technical specifications. Nevertheless the contracts between client and qualified contractor must be based on clear budgets and allow adjustments on the basis of fast decisions in the case of unpredictabilities. Hereunto a comprehensive and effective project management with appropriate expertise is indispensable, like at the Chemnitz projects.

Conclusion and Outlook

The technologies developed and applied by Baufeld and by other projects have been made possible a sustainable remediation of acid tar sites. Problems of those remediation processes which are known or might occur can be regarded as controllable. Applied technologies for material excavation, treatment and energy recovery can be taken into account in comparable projects. They also can be applied to other comparable sites and residues of the oil industry, which might be less problematic than the acid tar projects.

Figure 6: Reuse of the Neukirchen site as a location for PV plant

The implementation of the remediation concepts, provided in this article, allows a further long-term usage

of the remediated sites for improvement of infrastructure, urban and industrial planning. In order to gain such results as a prerequisite a co-burning unit for the residues must be established that operates continuously and economically for a long time, as it was proven by using the example of the Chemnitz project with the disposal way lignite-fired power plant for more than ten years.

Such advantageous constellation for an economic, sustainable and climate-friendly remediation, targeting for a regional energetic usage of the remediation products, is most likely unexisting, neither in Eastern Europe nor in oil producing countries. In order to overcome this problem of unsuitable conditions within the overall context of the responsibility of owners of contaminated sites and funding units regarding energy and social life Baufeld developed a technically innovative and economic concept for petroleum caused legacies. The concept is oriented on long-term goals and allows the implementation of the solution into regional sustainable waste management strategies. The concept is termed “Calorific Mining”.

The objective of the concept (www.calorific-mining.com) is to provide a system that allows using residues with a high heating value, recovered during a remediation process, for generation of electrical energy, heat and/or synthesis gas, in municipalities or industries. Key of the concept is the application of a specific technical plant based on a circulating fluidized bed. Technology and capacity of the equipment can be adapted to various qualities of residues, special local economic and most feasible targets and concepts of remediation as well as to the request of *electricity*, *heat* and *synthesis gas* of an industrial or municipal responsible organization.

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