We are a company of consulting engineers with a well-established international reputation. Our staff is planning and realising major and complex projects in the fields of infrastructure and environment. We have been a leading engineering company in Europe for decades and have realised successfully many waste and sludge treatment plants.

We offer the following services:

- Project development
- Project management
- Feasibility studies, expertises
  - Waste management concepts
  - Site selection and selection of appropriate technology
  - Technical due diligence
  - Operation, fault and risk analysis
  - Environmental impact studies
- Planning and realization
  - Complete plants
  - Process engineering
  - Electrical engineering and
    Civil construction including logistics
  - Quality management
  - Optimising operations
1. Introduction

The traditional way of sewage sludge disposal has always been agriculture, being the residue of civil waste water treatment a natural fertilizer. The up-coming presence in sewage water of heavy metals, especially in high industrialized regions, brought up the problem of soil contamination, hence the sludge with high metals content was disposed in landfills or thermal treatment plants.

In recent years other contaminants have caused apprehension, i.e. organic pollutants, including drugs and hormones, which can enter into the food chain, or pathogenic germs like BSE. The long term consequences of these micro pollutants to environment and human health are not yet clearly determined, hence political decision makers have introduced or think to introduce new regulations.
The result of above situation is an evolution in the methods of sludge disposal, still ongoing and by far not yet settled in the majority of European countries, with restrictions of the use in agriculture and a tendency to thermal treatments.

The aim of this article is to show possible solutions to this problem and the experience gathered in cases where they have been applied.

2. Trends of Disposal

In Switzerland long term sludge disposal strategy has been defined with federal regulations since the end of last century, which had foreseen a total ban on agriculture reuse and landfill disposal starting from 2008. This has brought to a trend on sludge treatment as shown in below Figure 1.

![Figure 1: Trends of disposal of sewage sludge in Switzerland](image)

The other European countries will most probably not adopt the same drastic solution as the Swiss government, but the general evolution will definitely follow this trend.

3. Ways of Sludge Disposal

As schematically shown in Figure 2 the disposal of sludge can occur biologically, thermally, chemically or a combination of them. As already mentioned in the introduction, the reuse of sludge in agriculture, although it represents a natural and good fertilizer, is going to be more and more restricted due to the known and not yet well known consequences on environment and health. Also the disposal in landfills has been or will be strongly restricted in the future, not representing anymore a sustainable way. As a result of above, alternative ways to agriculture and landfill must be identified.
Biological treatment will always be adopted as a preliminary treatment. Typically they are aerobic stabilization, anaerobic digestion and stabilization, biogas production and mechanical dewatering. The product of these treatments is a fairly stabilized organic material which has to be treated further until the organic part becomes completely mineralized and the remaining polluting substances brought to a stable and controlled form.

Mineralization of sludge can occur in two ways: thermally and chemically.

We designate as chemical process the so-called wet oxidation technique, which consists in bringing the sludge to high pressure and temperature, and adding oxygen to it. The so obtained conditions enable the oxidation of organic components. The out coming products are a mineralized slurry and oxidation gases. This interesting process has however till now not yet reached a sufficient proven reliability on an industrial scale.

Thermal processes have been applied since long time and have thus achieved a high reliability. There are various techniques, single or combined, which will be described more in detail in the next chapter.

4. Thermal Treatment Options

There are basically four alternative paths for thermal treatment of dewatered sewage sludge, as also shown in Figure 3:

- mono-incineration in individual furnaces,
- incineration in separate furnaces integrated in a waste to energy plant, with combined flue gas treatment,
- co-incineration with solid waste, in a waste-to-energy plant or a coal fired power station,
- drying + incineration in a cement work, a coal fired power station or any of above mentioned systems.
4.1. Mono-incineration

Herewith are meant plants and processes which are entirely dedicated to sewage sludge combustion. The technology by far the most common and employed is the fluidized bed combustion. These plants are fitted with an emission control system to remove pollutants from the flue gases and respect the emission laws.

There are simple products with capacities starting from 5,000 t/a dewatered sludge without heat recovery, as well as more sophisticated arrangements for higher capacities that are comprising pre-drying units and energy recovery facilities. A principle scheme of a fluidized bed combustion unit is shown in Figure 5.

There are some other technologies where the whole combustion process, instead of happening in one single space (the combustion chamber), is separated in two steps, pyrolysis first and combustion of pyrolytic gases after. First products on smaller scale are beginning to be offered on the market, but generally they do not have yet long term experiences.

4.2. Integrated incineration in a WtE-Plant

This option foresees the final treatment of sludge within a waste-to-energy plant. The combustion occurs in a separated and dedicated unit, but the flue gases are conveyed to the emission control system of the WtE plant and treated together. In this way there are interesting and profitable synergies. Hereafter are presented some examples of combustion systems integrated into a WtE plant.

4.2.1. Multi-stage furnace

This type of furnace consists of several fixed stages and an agitator at the centre. The sludge is fed to the top and drops from stage to stage as a result of being conveyed with the help of the agitator.
Whereas drying of the sludge takes place in the upper zone of the furnace, ignition and combustion occur in the lower parts. An additional energy source is required to ensure a temperature over 850 °C. The flue gas from the sludge incineration is fed to the waste furnace for post-combustion, and then treated in the emission control system along with the flue gas from the waste incineration. The external energy is partially recovered in the boiler.

![Image of Integrated multi-stage furnace](image)

*Figure 4: Integrated multi-stage furnace*

This solution allows a partial recovery of the external energy supplied to the multistage furnace.

### 4.2.2. Rotary kiln

This solution foresees the incineration of sludge in a rotary kiln combined with the incineration of solid waste. Part of the hot flue gas from the combustion chamber of the grate furnace is sent to the rotary kiln, where it flows in counter current to the sludge. After passing the drying zone, the sludge is incinerated in the hot region of the rotary kiln.

While passing through the drying zone of the kiln, the temperature of the flue gas drops to approximately 300 °C. The gas finally is fed back to the grate furnace for post-combustion. Here, complete oxidation of the organic residues occurs at approximately 900 °C.

An annual sludge amount of at least 5,000 tons of DS is required for an efficient combustion in a rotary kiln. For a satisfying burn out of slug, the rotary kiln requires sludge of constant quality.
4.2.3. Fluidized bed furnace

The fluidized bed furnace has already been described in chapter 3.1. The option shown here foresees the fluidized bed integrated into a WtE plant, giving the possibility to profit of the interesting synergies given by this combination.

Figure 5: Integrated rotary kiln

Figure 6: Integrated fluidised bed
The plant consists of sewage sludge input and storage facilities, fluidized bed furnace, boiler and electrostatic precipitator. To ensure auto-thermal combustion at temperatures of approximately 850 °C, the dewatered sludge is pre-dried up to 45 % DS by steam from the boiler. In addition to that, the sand bed is fluidized by pre-heated combustion air with temperatures up to 600 °C, using the sensible heat of the flue gas.

The mineral component of the sewage sludge is separated out from the flue gas in the electrostatic precipitator. Flue gas scrubbing and the reduction of nitrogen oxides are performed in the nearby MSW incineration plant.

### 4.3. Co-incineration in waste-to-energy plants

In co-incineration plants, dewatered or dried sludge is incinerated together with solid waste in a moving grate furnace. A good mixing of the sludge with the solid waste is crucial for problem-free operation.

Three different systems for feeding sludge into domestic waste incinerators are used:

- discharging to the solid waste bunker, mixing and lifting into the furnace feed hopper by the bunker's grab crane system,
- continuous pumping of dewatered sludge from a storage tank into the feed hopper,
- direct injection of sludge onto the moving grate.

To prevent the formation of slag with an unacceptable high organic content or increased fouling of the boiler, the addition of dewatered sludge should generally not exceed 15 % of the furnace's capacity.
4.4. Drying

Drying the dewatered sludge means bring it to a solid matter concentration of at least 90 %, that is a water content of not more then 10 %. Different types of dryers are used and proposed on the market:

- belt dryers,
- drum dryers,
- fluidised bed dryers.

Following Figure 8 shows a typical fluidised bed dryer.

Figure 8: Fluidised bed dryer

The necessary drying energy is normally produced by fossil fuels. Due to the massive rise of costs for fuels, this type of drying has become very expensive.

Recent studies for energy and cost optimisation have shown that two types of dryers will get advantage in the next future:

- contact dryers, heated by steam produced for instance in a solid waste incineration plant
- low temperature belt dryers, operated with a wastewater heat pump.

Dried sludge has not yet achieved its last destination stage. In fact, though more stable then dewatered sludge, it still contains the original organic matter which must be mineralized.

Thanks to its fairly high calorific heat value, which can vary depending on the organic content of the sludge between 7,000 and 14,000 kJ/kg, dried sludge is a good fuel which can be introduced into cement kilns or coal fired power stations. Alternatively it can also be fed into mono-incineration or integrated incineration plants, providing a certain disposal flexibility.
5. Phosphor Recovery

One of the essential elements for plant growth is phosphor, an elementary material whose stocks on earth are limited and forecasts of experts indicate that it will become dramatically scarce in the next decades. Since it is an elementary chemical component, it cannot be reproduced, and it is neither possible to substitute it with anything else. Hence a rising attention is being given to this issue.

Sewage sludge contains considerable amounts of phosphor, with concentrations of 3-4 % of dry matter. For this reason it has been for long times widely used in agriculture as a fertilizer, as already mentioned in the introduction. That was a direct recovery of phosphor in agriculture.

Now days, with the up coming problems described in this article, direct recovery is going to be gradually restricted. The alternative way is to recover the phosphor from the sludge combustion ashes, where phosphor concentrations is likely to reach 5-8 %

First chemical processes to recover phosphor from ashes are already successful on the small scale and the development to bigger scales is technically feasible. The problems at the moment are of economic nature, i.e. the cost of recovered phosphor from sludge ashes are still far too high compared to actual market prices.

However this situation can soon change, with rising market prices of phosphor due to its penury and the risk of insufficient worldwide food production. That is why Swiss government is going to introduce a new regulation allowing only those sludge treatment processes which can guarantee a future phosphor recovery.

Considering thermal treatment options as presented above, only those solutions where sludge ashes are collected separately and thus can be in future sent to a phosphor extraction facility will be allowed. That is:

- mono-incineration
- integrated incineration
- drying + combustion in mono or integrated incineration

In all other options sludge ashes are mixed with other ashes (coal, waste) or integrated in cement, hence without a realistic possibility to recover phosphor out of it.

The government of canton Zurich has recently decided to build a new sludge treatment facility with mono-incineration and to create a dedicated landfill for the sludge ashes. This will be a temporary storage until the recovery of phosphor out of the ashes will become economically convenient. It is in other terms an investment for the future.

6. Comparison of Treatment Options

In following table 1 the main features of the presented options are reported.

Factors which have an influence on the costs are for instance:

- size of the plant: mono-incineration for instance is not convenient for smaller quantities, whereas it can become interesting above a size of 30,000 t/a (25 % DS)
- already existing facilities
- implemented machinery: type of furnace, flue gas treatment system (depending also on local environmental prescriptions)
• energy costs: type of external energy used, electricity price
• residues disposal costs
• sludge transportation costs: distance between water treatment and sludge treatment plant.

Table 1: Main features of sludge treatment options

<table>
<thead>
<tr>
<th>Treatment option</th>
<th>Total costs</th>
<th>P-recovery</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mono incineration</td>
<td>medium-high</td>
<td>yes</td>
<td>Total autonomous solution</td>
</tr>
<tr>
<td>Integrated incineration in WtE plant</td>
<td>medium</td>
<td>yes</td>
<td>Presence of WtE plant necessary</td>
</tr>
<tr>
<td>Co-incineration in WtE plant</td>
<td>low</td>
<td>no</td>
<td>Presence of WtE plant necessary Only limited sludge quantities</td>
</tr>
<tr>
<td>Co-incineration in coal fired power plant</td>
<td>low</td>
<td>no</td>
<td>Dependency on coal power plant</td>
</tr>
<tr>
<td>Drying + combustion in cement kiln or coal fired power plant</td>
<td>medium-high</td>
<td>no</td>
<td>Dependency on cement factory or coal power plant Interesting for long transport distances</td>
</tr>
<tr>
<td>Drying + combustion in mono or integrated incineration</td>
<td>medium-high</td>
<td>yes</td>
<td>Interesting for long transport distances</td>
</tr>
</tbody>
</table>

Cement factories and power stations are private owned facilities, therefore the possibility and the conditions for sludge delivery to these plants can change depending on non influenceable factors. WtE plants are on the contrary often public owned, therefore the dependency on them implicates less risks.

Generally speaking, there is not one absolute best solution for the sludge treatment, but there are best solutions for each single situation depending on its specific framework conditions.

7. Conclusions

In the near future sensibility on problems due to sewage sludge reutilization in agriculture will probably increase in the European countries, thus claiming for alternative disposal ways.

Solutions for sludge processing alternatives are available and technically fit. The selection of optimal solution must take into account:

• local and regional conditions
• capacity demand
• existing facilities.

Phosphor recovery from sludge will as well become a sensible issue and hence influence the choice of best solutions.

Since the realisation of necessary facilities is often a long lasting process, not at last because of public opposition, decision makers are invited to start soon with the definition of the most adequate strategy and set up a long term program for its implementation.
8. Summary

The use of sewage sludge in agriculture is being questioned, in particular because of the inorganic and organic pollutants, including traces of drugs and hormones. Therefore, restrictions are gradually being introduced in European countries, with a trend towards mineralization of sludge and hence solutions envisaging thermal treatments. There are different reliable options available, the most interesting one depending on the specific framework conditions of each situation. One of the selective factors is the possibility to recover phosphor out of sewage sludge, an essential element for the plant growth whose earth stock is going to become scarce, and the lack of which could seriously affect global food production.