

CURRENT STATUS OF ALTERNATIVE FUEL USE IN LIME KILNS

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ABSTRACT

Lime kilns consume large amounts of fossil fuels. Due to the steady rise in natural gas and fuel oil costs in recent years, there is a need for mills to find more economical fuel alternatives that have minimal impacts on lime kiln and chemical recovery operations. This paper examines the technical feasibility of various alternative fuels, including petroleum coke, directly fired or gasified wood residues, precipitated lignin, bio-oil and olein biofuel. Since each fuel has a different composition, heating value and burning characteristic, it is important to understand the pros and cons of burning each fuel before implementing it in the lime kiln.

INTRODUCTION

In kraft pulp mills, lime kilns are used to convert lime mud (CaCO_3) to lime (CaO) for reuse in the causticizing plant. The process requires a large amount of heat, which is supplied to the kiln mainly by burning either natural gas or fuel oil. Depending on the kiln design and refractory type, and whether it is equipped with product coolers or with a lime mud dryer, an average lime kiln may require 6 to 10 GJ of heat per tonne of CaO production. At the current natural gas price of \$US 8/GJ, the energy cost for a typical lime kiln is about 13.5 USD/ADMT, or about 4 to 7 million USD/year at a 1000 ADMT/d kraft mill.

About two-thirds of the kilns in the United States and Canada burn natural gas and one-third burn fuel oil. Along with these fossil fuels, many kilns also burn waste streams and by-products from various mill processes, such as concentrated non-condensable gases (CNCG), stripper off gases (SOG), crude tall oil and hydrogen. These auxiliary “fuels” typically provide 5 to 10% of the total heat requirement. Due to high energy costs in recent years, there is a need to find alternative fuels that are more economical than traditional fuels and have minimal negative impacts on the operation of the lime kiln and the pulp mill. A number of alternative fuels have been used in lime kilns such as petroleum coke in the US and syngas from gasified bark and sawdust in Sweden and Finland.

The objective of this work is to gather information about alternative fuels currently available for lime kilns and to use this information to examine the impacts on lime kiln and mill operations. The work involves visiting mills using alternative fuels, developing a dynamic material and energy balance model for a lime kiln burning various fuels and using the model to conduct an economic analysis of alternative fuel burning. This paper discusses the major alternative fuels that are currently used in the industry, and the pros and cons of their use.

ALTERNATIVE FUELS

Around the world, various alternative fuels are being used or proposed for use in lime kilns, including:

- Petroleum Coke
- Wood Biofuels
 - Directly fired wood residues (bark, sawdust)
 - Gasified wood residues (bark, sawdust)
 - Precipitated lignin
 - Pyrolysis oil (Bio-oil)
- Olein Biofuel

Petroleum Coke

Petroleum coke (or petcoke) is a by-product of the oil refining process. It is a solid fuel that consists mainly of carbon (85 to 90 wt%) and an appreciable amount of sulphur (5 to 7 wt%), and has a higher heating value (HHV) of about 35 MJ/kg (15,000 Btu/lb).

Petcoke comes in as solid lumps, which need to be pulverized into fine powder before being fed into the lime kiln burner. The two major capital equipment items required for pulverized petcoke burning are a petcoke storage and feed system and a multi-fuel firing burner. For mills that opt to receive raw petcoke, they will also need to install a grinding mill, although most new installations are receiving pulverized petcoke since supplies of raw petcoke are generally not available. Currently, 17 mills are continuously firing petcoke in their lime kilns. These mills are located predominantly in the southeastern US. Three of these mills have been burning petcoke for over 20 years, and the remaining 14 mills have begun their use of petcoke since 2004. Petcoke typically substitutes 25 to 85% of the traditional fuel depending on permit and equipment limitations. In addition, there are 2 active petcoke trials and at least 2 more trials planned before the end of this year.

The primary driver behind the use of petcoke in lime kilns is its lower cost, which for pulverized petcoke may vary from 3.8 to 4.7 USD/GJ (4 to 5 USD/MMBtu) depending on transportation distance from the petcoke supplier to the mill. The price is not expected to change significantly due to the increased output of petcoke from the oil refineries [1]. The payback period for a petcoke system is about 2 to 3 years when the cost of traditional fossil fuels exceeds that of petcoke by 2.8 USD/GJ (3 USD/MMBtu) [2]. One consideration for the long-term, however, is the possibility that future carbon taxes imposed on pulp mills may reduce the energy cost savings of petcoke. Consumer-based carbon taxes on fossil fuels are common in Northern Europe and is scheduled to begin in British Columbia, Canada, as of July 1, 2008.

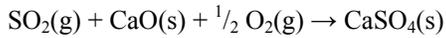
There are a number of operational concerns that must be taken into consideration when implementing petcoke in lime kilns. Petcoke is relatively difficult to burn due to its lack of volatiles and thus is usually burned in combination with natural gas or fuel oil. Since combustion occurs at the surface of petcoke particles, a finer grind provides a higher surface area and allows for higher rates of traditional fuel substitution. It is important to ensure that petcoke is burned completely; otherwise residual carbon may end up in the lime mud, in white liquor suspended solids, and possibly in the pulp.

Petcoke also yields a higher flame temperature than fuel oil or natural gas. This may lead to increased front end temperatures and consequently an increased risk of refractory damage. The high flame temperature and the relatively high fuel nitrogen (N) content in the petcoke may also result in higher NO_x emissions from the kiln stack. These problems, however, may be negated using properly designed burners and/or improved front-end temperature control systems.

Most of the non-process elements (NPEs) introduced with petcoke are usually not a concern. Thanks to the high alkalinity of the kraft liquor, heavy metals such as Pb, Zn, Cr, Fe, etc. are expected to form insoluble oxides or sulphides and be removed from the liquor system with grits and with lime dust disposal. Silica and alumina contents in the petcoke are usually small and are not expected to cause a problem. Vanadium may be problematic due to the high corrosivity and volatility of vanadium compounds and their possible contribution to superheater corrosion in the recovery boiler, although there is no evidence that this has occurred. A field study conducted in early 1990's at a kraft mill where petcoke was burned in lime kilns confirmed the presence of a high V concentration (250 ppm) in black liquor [3]. However, the study also concluded that the high V concentration was not the cause of severe superheater corrosion experienced in the recovery boiler at the mill. In a recent laboratory study, no significant difference in corrosivity was found between deposits that contained no V and those contain 2 wt% V₂O₅ [4].

The biggest concern over petcoke burning in lime kilns is the high sulphur (S) content, which is typically about 5 wt%. Although the fate of S that enters the kiln with petcoke is not well understood, based on mill experience and the current understanding of the process chemistry, one can reasonably speculate where S may end up and what impact it may have on the recovery operation.

In the kiln, S is oxidized to sulphur dioxide (SO₂), which reacts readily with calcium oxide (CaO) in the lime to form calcium sulphate (CaSO₄), Reaction 1.



[Reaction 1]

Despite the abundance of lime in the kiln, not all the SO₂ produced can react with lime due to the poor gas-solid contact in the kiln and the low surface area of lime nodules. Depending on the fuel S content, kiln operating conditions and lime mud characteristics, a portion of SO₂ may pass through the kiln without reacting and contribute to increased SO₂ emissions. In a study of the effect of burning high S containing CNCG on the performance of an oil-fired lime kiln that was equipped with a lime mud dryer, the SO₂ emissions from the kiln stack were found to increase markedly from a base value of 20 to 30 ppm when the kiln was co-fired only with SOG (mostly methanol) and no CNCG, to about 520 ppm when CNCG were also burned [5]. The S balance, expressed in kg/t CaO, for this kiln during the study is shown in Figure 1.

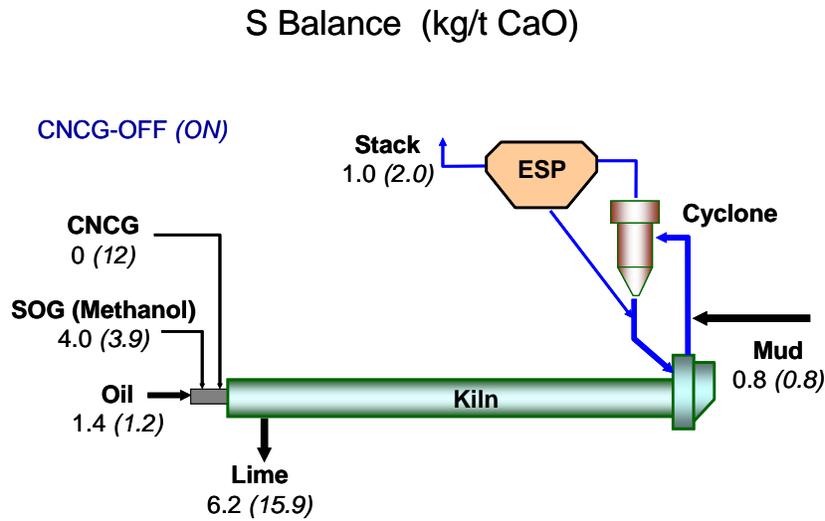


Figure 1. Effect of CNCG Burning on Sulphur Balance of a Lime Kiln equipped with LMD [5].

Based on the total amount of S entering the kiln with mud and fuel (oil, SOG and CNCG) and the amount of S leaving the kiln with lime, the S capture efficiency (i.e. the ability of lime to absorb S in the kiln) can be calculated. It was 98.2% when the total S in the fuel was 5.4 kg/t CaO, but decreased to 88.7% when the total S in the fuel was 17.1 kg/t CaO.

For a hypothetical lime kiln that burns only petcoke (or 100% substitution rate) containing 6 wt% S, the total S input with petcoke is about 10 kg/t CaO. If the above sulfur balance obtained from the CNCG burning kiln is also applicable to the case of petcoke burning, there should be an insignificant increase in SO₂ emissions for kilns that burn petcoke at a substitution rate of below 50%, which is the case for many kilns. For kilns that are equipped with flue gas scrubbers, SO₂ emissions are a non-issue since most of the remaining SO₂ in the flue gas would be absorbed in the scrubber solution. On the other hand, for kilns that burn petcoke at higher substitution rates, or petcoke together with CNCG and SOG, high SO₂ emissions are inevitable, particularly for kilns without scrubbers.

The high S capture rate of the lime implies that most of the S entering the kiln with petcoke will be converted into CaSO₄ and remain in the returned lime and in the lime dust. This will lower the lime availability at a rate of about 0.16% per kg/t CaO of S input, and increase the requirement of makeup lime by the same amount. The high S capture rate also causes the rapid formation of hard deposits on the kiln wall, which may lead to ringing problems in some lime kilns [6]. Furthermore, since CaSO₄ is formed mostly on the lime surface and is relatively insoluble in water, it hinders the contact between CaO in the lime, water and Na₂CO₃ in the liquor, making the returned lime less reactive, more difficult to slake and making it settle more quickly in the slaker. As a result, CaSO₄ is enriched in grits and in lime dust, and thus is removed from the liquor system with grits and lime dust disposal.

In the slaker and causticizers, the slaking and causticizing reactions cause lime nodules to breakup into smaller particles and to release CaSO₄ to the liquor. The “released” CaSO₄ reacts rapidly with sodium carbonate (Na₂CO₃) in the liquor to form calcium carbonate (CaCO₃) and sodium sulphate (Na₂SO₄), according to Reaction 2.



The precipitated CaCO₃ is essentially lime mud. This increases the mud load to the causticizing plant and the lime kiln, and thus offsetting the need for makeup lime. Na₂SO₄, on the other hand, is water-soluble and ends up leaving the causticizing plant with the white liquor, becoming part of the sulphate dead load in the liquor cycle. Na₂SO₄ eventually enters the recovery boiler where most of it is reduced to Na₂S. This process inevitably results in an increase in liquor sulphidity.

Note that the S/Na₂ molar ratio of Na₂SO₄ is 1, while that of the kraft liquor is much lower, 0.2 to 0.4, depending on the mill sulphidity. This means that mills will have two options: i) operating at a higher sulphidity, or ii) keeping the same sulphidity and the same total titratable alkali (TTA) by purging lime dust (enriched in CaSO₄) and/or recovery boiler precipitator dust (enriched in Na₂SO₄), and by adding Na makeup at an amount equivalent to that lost with the dust purge. While Option i) is simple, it changes the liquor characteristics and may not be feasible for some mills. Option ii) does not affect liquor characteristics, although its requirement of Na makeup may incur significant costs, and this must be taken into account when using petcoke. The combination of the two options is probably a better solution.

It is difficult to estimate how high the liquor sulphidity may reach and how much Na makeup may be required as a result of burning petcoke in the lime kiln. These depend on many factors including the S capture efficiency of the kiln, the kinetics of the Reaction 2, the amounts of grits and lime dust disposal, and the amount of S loss through SO₂ and particulate emissions from recovery boiler and lime kiln stacks.

Petcoke does offer operational advantages in addition to the significant fuel cost savings. Kilns fired with a 75% petcoke-25% natural gas mix have a similar temperature profile to kilns fired with 100% fuel oil. They are also more responsive to control actions than kilns fired with 100% natural gas, produce higher concentrations and flow rates of CO₂ for downstream precipitated calcium carbonate (PCC) plants, and they tend to be less dusty, probably due to better sintering of lime nodules [1] and the formation of CaSO₄ on the lime surface in the burning zone.

Gasified Wood Residues

Gasification is a thermal process that converts carbon (C) and hydrogen (H) containing solid fuels into gases, which can displace natural gas or fuel oil in boilers, dryers and lime kilns. In an oxygen-lean atmosphere at high temperatures, C and H in solid fuels can be gasified into combustible gases (H₂, CO and hydrocarbons). The resulting gases (syngas) also contain CO₂ and H₂O, and contain N₂ if air is used for gasification.

Syngas produced from wood residues has been proposed for use as a lime kiln fuel because it offers the benefits of a renewable non-fossil fuel that reduces CO₂ emissions and has proven in some cases to have economic benefits. One of the major concerns with syngas from wood residues, however, has been its low heating value compared to natural gas or fuel oil. Depending on the gasifier operating conditions, wood residue type, moisture content, and on whether O₂ or air is used, the higher heating value of syngas may vary widely, from 3.5 to 11.5 MJ/kg (1500 to 5000 Btu/lb); compared with 53.2 MJ/kg (22,300 Btu/lb) for natural gas and 43.1 MJ/kg (18,400 Btu/lb) for fuel oil. The low heating value means that more fuel is required to achieve the same heating rate, leading to greater amounts of exit gases going to the flue gas handling system and the possibility of exceeding the system capacity. In addition, a higher gas flow rate through the kiln can also lead to increased gas velocities, which may cause more dusting to occur and put an additional strain on the flue gas handling system. Other challenges include lower flame temperatures, temperature profiles that differ from those of natural gas and fuel oil, and introduction of NPEs into the kiln, particularly when the cyclones are ineffective, allowing ash and particulates to enter the kiln along with the syngas. The economics of this alternative fuel option vary greatly depending on oil and natural gas prices, but also on transportation costs. The mills that gasify sawdust, for example, are typically located close to the sawmill that is the source of the fuel.

Commercial wood residue gasifiers for use in lime kilns were built in the 1980's by Ahlström at mills in Sweden, Finland and Portugal. The gasification systems included a wood residue feeding system, drum or pneumatic dryer with an accompanying hot gas generator, gasifier and cyclone separator. The designs strived for 100% fuel substitution, thus requiring the use of biomass dryers to ensure that the gasifier produced syngas with a sufficiently high heating value. Many have suffered from low availability due often to problems in the dryers and feed systems rather than in the gasifiers themselves. A number of these mills have since ended their use of gasifiers, particularly after the oil prices decreased in the late 1980's and 1990's.

Wood residue gasifiers today are offered by a number of suppliers and come in different types. Fluidized bed type gasifiers have been used for lime kiln, boiler, power plant, and district heat applications. These gasifiers are usually either bubbling fluidized bed (BFB) or circulating fluidized bed (CFB) type. They can be operated at low pressure or high pressure, and with oxygen or air. The low pressure CFB gasifiers fed with air are typically used in lime kiln applications. An example of how a CFB gasifier may be integrated with a lime kiln is shown in Figure 2.

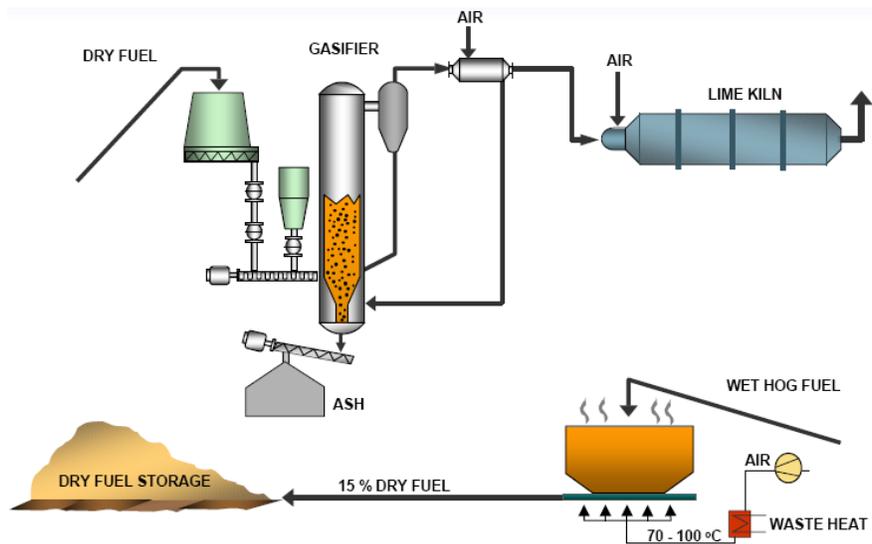


Figure 2. Schematic of a CFB gasifier integrated with a lime kiln (Courtesy of Carbona Inc.)

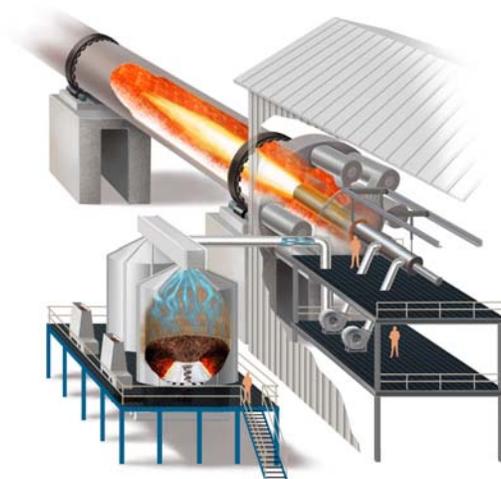


Figure 3. Schematic of a fixed bed updraft gasifier integrated with a lime kiln (Courtesy of Nexterra Energy Corp.)

Another type of gasifier being offered for thermal heating, cogeneration, boiler and lime kiln applications is the fixed bed updraft type (Figure 3). Design simplicity, low capital and operating cost, clean syngas (low particulate and NO_x emissions) and fuel flexibility (up to 55% moisture) have been cited amongst the technology's advantages.

The new generation of gasification systems for lime kiln applications has been fitted with improved feed systems, to avoid the availability problems that the installations from the 1980's have been subject to. A number of other improvements are being implemented in the area of wood residue drying. In most designs wood residue dryers are installed before the gasifier to lower the feed moisture, allowing for higher syngas exit temperature and heating value. Tar in the syngas is also an important consideration. The amount and composition of tar varies with wood residue composition, gasifier type and operating parameters. In general, entrained flow gasifiers produce tar-free gas due to their high temperatures; fixed-bed downdraft gasifiers produce gas with a low tar content; fixed-bed updraft gasifiers produce relatively high tar concentrations in the outlet gas; while fluidized bed gasifiers produce significant, but variable, amounts of tar [7]. As the gas cools down, the main challenge is to ensure that tar stays in the gas phase in the pipelines that connect the gasifier to the kiln burner. Condensed tars can clog up the equipment and are difficult to remove. The key to preventing tar condensation is to minimize heat losses through the piping and to ensure that the syngas exits the gasifier at a sufficiently high temperature, which is one of the reasons for the need to dry the wood residue feed prior to gasification.

New drying options are now available to help overcome the mechanical component failures and fire safety availability issues experienced in older dryers. One example is low temperature belt dryers. These systems use mill waste heat sources to heat up air, which in turn contacts the biomass on conveyor belts in a cross-current fashion. The low temperature operation (relative to that of pneumatic and drum dryers) has the advantage of reducing fire/explosion risks and minimizing VOCs generated from the biomass. Other dryer options include rotary dryers heated indirectly by mill waste heat sources, or if waste heat is not available, hot gas generators fuelled by syngas or fossil fuels may be used as a heat source for the dryer. It is important to note that the most suitable dryer type will depend on the waste heat source availability at the mill.

Two mills in Sweden are still running their biomass gasifiers from the 1980's. Mill A has two lime kilns: one burning oil and the other burning syngas from a biomass gasifier, which provides an excellent opportunity for comparisons. Their sawdust-fed CFB gasifier has been in operation since 1985. Mill B has operated its bark-fed CFB gasifier since 1987. The mill has one lime kiln that typically burns about 95% syngas and the remainder fuel oil. The gasification plant at each mill consists of a biomass storage and feed system, a biomass dryer and related equipment, and a CFB gasifier, as schematically shown in Figure 4. In both cases, the dryer is fuelled by the syngas produced, and usually about 25% of the syngas is used for this purpose.

Similar to most of the other biomass gasifier installations of the 1980's, the gasification plants at these mills have struggled with availability and long downtimes over the years mostly due to problems related to their feed systems and dryers. Despite the consistent availability problems, the mills have still saved money on lime kiln fuel costs.

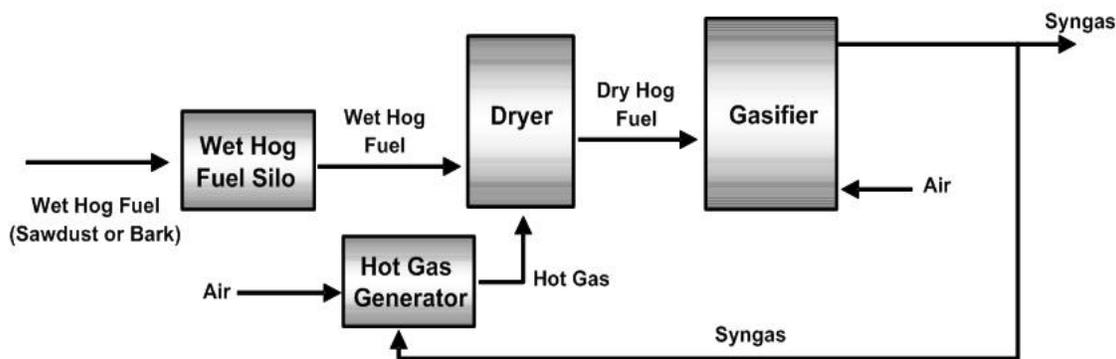


Figure 4. Typical Gasifier System Schematic

A number of operational observations were made over the years at Mill A. The smaller kiln that fires oil has a hotter flame than the larger kiln, with the syngas flame being almost 200°C cooler than the oil flame. The flame is longer and more stable with the syngas than with the oil. The operation is smoother with syngas, but it is harder to control the temperature because the response time with the syngas flame is slower than that of the oil flame.

Mill B reports a difference in lime quality between burning oil versus syngas: the lime availability is lower with the syngas because of the magnesium and phosphorus that comes in with the bark. This is mainly because the cyclone is inefficient and allows ash/particulate into the kiln with the syngas.

Directly Fired Wood Residues

In response to the high oil prices in the 1980's, some Scandinavian mills began to directly fire powdered wood residues (sawdust or bark) into their lime kilns as a simpler alternative to biomass gasification. The heating value of the wood residues is typically about 19 to 22 MJ/kg (8200 to 9500 Btu/lb) on a dry basis. The basic requirements for this fuel option are low moisture residues and the use of more purchased lime to control the NPEs that come in with the residues. The drying system usually consists of wood silos, a grinder, a hot gas generator and a dryer. The design issues and considerations for the directly fired wood system dryers are similar to those of gasified wood dryer systems. The major disadvantages of this option are the low returned lime availability and high power consumption and mechanical wear in the grinder.

The first system was installed at the Smurfit Kappa Mill (formerly Lövhölmén) in Piteå, Sweden, in 1979. Another system was also installed in Sweden at Södra Cell's Mönsterås Mill in Mönsterås in 1985. Both installations are still in use today.

Precipitated Lignin

Separating lignin from black liquor and burning it in lime kilns has been advocated since the late 1980's by researchers at Paprican and the University of British Columbia in Canada. This body of work included computer-based simulations and subsequent pilot scale kiln trials for replacing fossil fuels with precipitated lignin in lime kilns [8,9,10].

More recently, the LignoBoost Process, which was jointly developed by STFI and Chalmers University in Sweden, has been commercialized. In this process, lignin is separated from the black liquor using acid precipitation and ultrafiltration. The precipitated lignin consists mostly of carbon, oxygen, sulphur and hydrogen. It is usually dried to 70% dry solids and has a heating value of 24.4 MJ/kg (10,490 Btu/lb) on a dry basis.

Lignin precipitation has an added advantage for mills where the recovery boiler is thermally limited and is the bottleneck for the mill production capacity. The heat load of the recovery boiler is roughly proportional to the amount of lignin sent in the black liquor, and thus reducing the amount of lignin sent to the recovery boiler via precipitation can help to debottleneck the system [11]. One of the challenges in firing lignin in the kiln, however, is to ensure that the lignin is washed thoroughly to reduce the sodium content to an acceptable level. This is important not only for minimizing chemical losses [11] but also for avoiding possible problems with ring and ball formation in the kiln [8].

Precipitated lignin has not yet been used commercially in lime kilns, but is well on its way. A pilot-scale study on precipitated lignin combustion has already been conducted, and a full scale trial on a lime kiln is scheduled for later this year at a mill in Sweden.

Wood Pyrolysis Oil (Bio-Oil)

Wood pyrolysis oil (or bio-oil) is produced by thermally degrading (or pyrolyzing) the organic components in wood residues in the absence of oxygen at temperatures of about 400 to 500°C. The initial products of this pyrolysis process are char and volatiles, which are condensed to form bio-oil. In contrast to traditional way of producing charcoal, the process parameters for the modern fast pyrolysis process are designed to give high yields of pyrolysis oil rather than char. Bio-oil is a dark brown or reddish-brown liquid with a smoky odour.

Bio-oil may be used as a fossil fuel substitute for heat and power, lime kiln and boiler applications. It has a higher heating value of 16 to 19 MJ/kg (6900 to 8200 Btu/lb) and a water content of about 20 wt%. Bio-oil consists of over 100 compounds, but ultimately contains mainly C, H and O, and is essentially sulphur-free.

Tests conducted using the pilot lime kiln at the University of British Columbia, Canada, showed that bio-oil atomizes and burns well, yielding a flame comparable to that of natural gas. The results also showed that the temperature and calcination profiles were similar and the lime reactivity was not affected. Tests performed by bio-oil supplier Dynamotive in a BFB pyrolyser pilot facility in West Lorne, Ontario, Canada show that the levels of CO, SO₂ and NO_x in off-gases are comparable to those of natural gas.

Ideally, a bio-oil production facility would be located in an area with a large supply of biomass available, on the order of 200 bone dry t/d. The resulting bio-oil can be used at the facility, or easily shipped via tanker trucks, since the reduced volume of pyrolysis oil relative to raw biomass (a 12:1 volume ratio) allows for economical short-term storage and transport and the possible sale of excess oil to other users. Therefore, pulp mills would have the option of shipping in bio-oil or producing it on site.

To date, there has not yet been a commercial implementation of pyrolysis oils in a lime kiln, although a short-term field test has been done at a pulp mill in British Columbia, Canada, and reportedly has shown the thermal performance and lime quality to be comparable to that of natural gas. There are some possible concerns with bio-oil pH and viscosity [12], which likely will be addressed as trials continue.

Olein Biofuel

A kraft pulp in Brazil is currently burning filtered, liquefied animal fat from a nearby meat processing plant in their lime kiln. The fuel is an oil derived from animal fat called olein. Olein is made up of a variety of fatty acids, but ultimately it consists mostly of carbon, hydrogen and oxygen, and contains virtually zero NPEs. Olein biofuel has a higher heating value of 39.3 MJ/kg (16,900 Btu/lb).

The mill has conducted tests to characterize the biofuel before burning in order to achieve the correct tuning of burner system and to avoid plugging or overheating in fuel piping. They have not had to replace their pumps or burner because through temperature control they have managed to lower the viscosity of the olein biofuel to the same as that of the heavy oil they were previously using. They also report that the use of olein biofuel has reduced deposition in pipes, pumps and the burner since it is more similar to light oil than heavy oil. The kiln temperature profile, flame length, lime reactivity and lime availability is comparable to that of heavy oil and the mill is saving significant money on fuel costs.

SUMMARY

A variety of alternative fuels are being used or being proposed for use in lime kilns, each of which have different process impacts on the lime kiln and chemical recovery cycle that should be examined prior to implementation. While petcoke is the most common alternative fuel in the US due to its high heating value and low cost, it has several disadvantages, in particular problems associated with high sulphur input in the mill recovery system. Gasified wood residues, directly fired wood residues, bio-oil and precipitated lignin all have the benefit of being renewable non-fossil fuels that reduce CO₂ emissions, yet all have the disadvantage of having lower heating values relative to fossil fuels, which impacts kiln production and performance.

Given the fact that the optimal alternative fuel choice varies from mill to mill, the challenge for the pulp and paper industry is to gain a better understanding of the unique process and operational impacts of each fuel, so as to allow mills to efficiently and effectively select the best fuel alternative for their particular situation.

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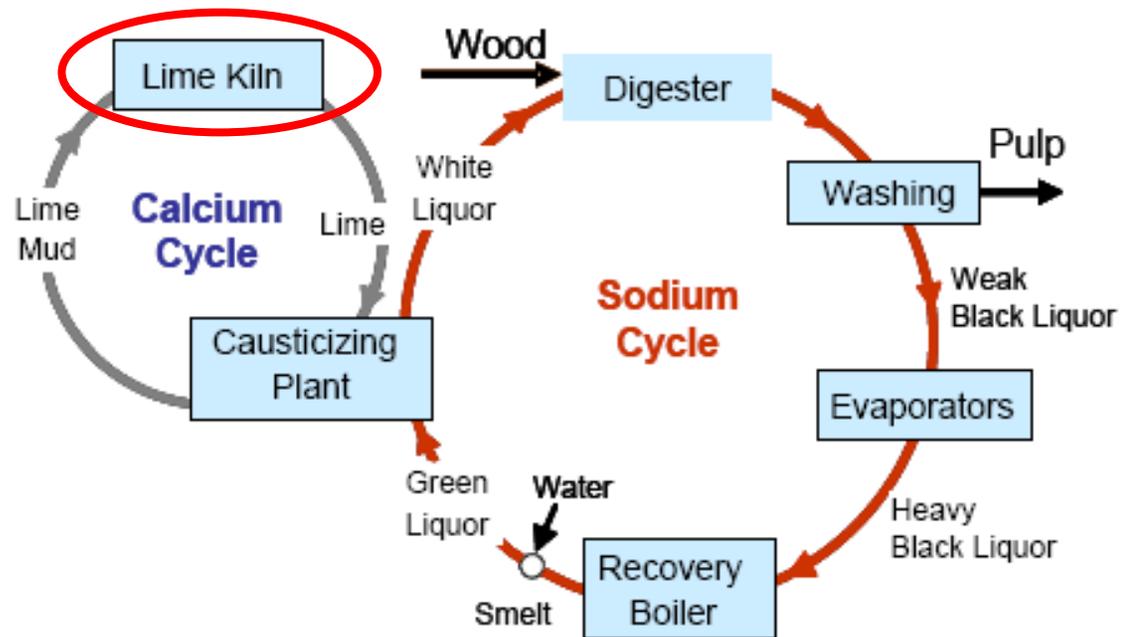


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**2008 TAPPI EPE Conference
August 27, 2008
Portland, OR**

Motivation

- Lime Kiln: only place in kraft pulp mill that predominantly uses fossil fuels
- Currently in North America:
 - 2/3rd natural gas
 - 1/3rd fuel oil

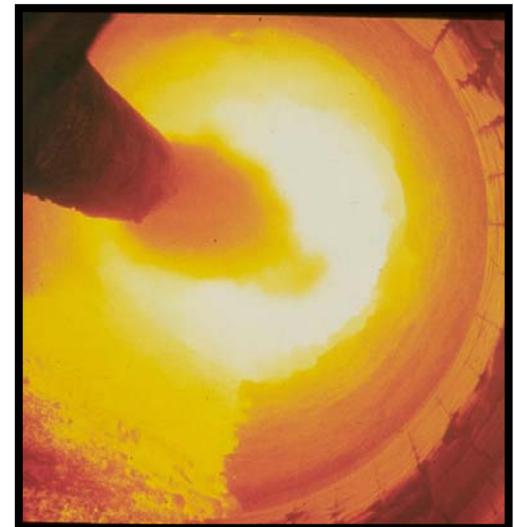


Kraft Chemical Recovery Cycle

Motivation

Heat Requirement	6-10 GJ/tonne CaO
Kiln Energy Cost*	over \$US 6,000,000/yr (1000 ADt/d Kraft Mill)

***Fuel prices have been increasing
and are not expected to return to
their previous levels***



* Based on the natural gas price of \$US 8/GJ

Motivation

- Global tendency: alternative fuels to cut production costs
- Many options available, difficult for mills to choose which to implement
 - Different Fuels = Different Process Impacts
 - Unique Pros and Cons

Major Objective

To gather information about alternative fuels currently available for lime kilns

- Impacts on Lime Kiln and Mill Operations
 - Technical and Economic Feasibility



Lime Kiln Fuel Alternatives

- Petroleum Coke
- Wood Biofuels
 - Directly Fired Wood Residues (bark, sawdust)
 - Gasified Wood Residues
 - Precipitated Lignin
 - Pyrolysis Oil
- Olein Biofuels

Natural Gas: ~53 MJ/kg

Fuel Oil: ~43 MJ/kg

Directly Fired Wood Residues

- High oil prices of 1980's, simpler alternative than gasification
- Powdered sawdust or bark
- Typical HHV: 19-22 MJ/kg
- Disadvantages: accumulation of NPE's in lime, high power consumption, high mechanical wear
- Installations:
 - Smurfit Kappa Mill (formerly Lövholmen) in Piteå, Sweden, 1979
 - Södra Cell Mönsterås Mill in Mönsterås, Sweden, 1985



Precipitated Lignin

- Pioneering work at Paprican in late 1980's
- LignoBoost Process (STFI, Chalmers University)
- Lignin separated from black liquor using acid precipitation and ultrafiltration
- Dry basis HHV: 26.7 MJ/kg (LHV: 25.4 MJ/kg)



Precipitated Lignin

- Lignin Precipitation: advantage for mills with thermally limited recovery boilers
- Sufficient washing (esp. of Na) required to minimize chem losses, avoid ring/ball formation
- Plans for full scale lime kiln trial in Sweden this year

Wood Pyrolysis Oil (Bio-Oil)

- Pyrolysis = thermal degradation of organics in biomass in absence of oxygen
- Fossil fuel substitute
- HHV: 16-19 MJ/kg (water content of 20%)
- Comparable to natural gas in:
 - Thermal performance, lime quality, Off-gas levels of CO, SO₂, NO_x



Courtesy of Dynamotive Energy Systems Corp.

Olein Biofuel

- Derived from animal fat, olein
- Oily, viscous liquid with a pale yellow appearance
- HHV: 39.3 MJ/kg
- Brazilian Mill
 - Filtered, liquefied animal fat from nearby meat processing plant
 - Saving significant money on fuel costs

Petroleum Coke

- Petroleum coke: is a by-product of the oil refining process (a.k.a. petcoke)
- Solid fuel that comes as lumps
- Pulverized and directly fired into the lime kiln
- Typical traditional fuel substitution: 50-85%



Petroleum Coke

- Used predominantly in Southeastern US
 - Currently 17 mills using petcoke in lime kilns
 - 3 mills for 20+ years
 - 14 more mills since 2004
 - 4 trials this year

Petroleum
Coke



Pulverized
Petcoke

Courtesy of DTE Petcoke

Composition and Heating Value

Component	% by weight
Moisture	0.25
Carbon	86
Sulfur	6.5
Hydrogen	3.5
Nitrogen	2
Oxygen	1.35
Ash	0.4
Trace Elements: V, Ni, Ca, Si, Fe, Na, Mg, Al, F, Cu, Mn, Se, Be, Pb, As, Cd, Hg	
HHV: 34.8 MJ/kg (15,000 Btu/lb)	

Petcoke Pros and Cons

PROS:

- Low Price
- High heating value
- For a 75% petcoke – 25% natural gas mix:
 - Temperature profile similar to 100% oil
 - More responsive to control actions than NG kilns
 - Often less dusty

CONS:

- Difficult to burn (low volatiles)
- Higher flame T, increased NO_x and risk of refractory damage
- Increased Sulfur, NPE's (especially Vanadium)

Effects of High Sulphur Fuel Use

- Petcoke sulphur content ~6 wt%
- Important concern for petcoke burning in kiln
- Fate of fuel S entering kiln not well understood
- Reasonable speculation based on current understanding of process chemistry can be made
- Potential impacts on lime kiln and chemical recovery operations

Gasified Wood Residues

- Gasification: air starved process that uses heat to convert organics in solid fuels to syngas
- Fossil fuel replacement
 - Boilers
 - Dryers
 - Lime kilns

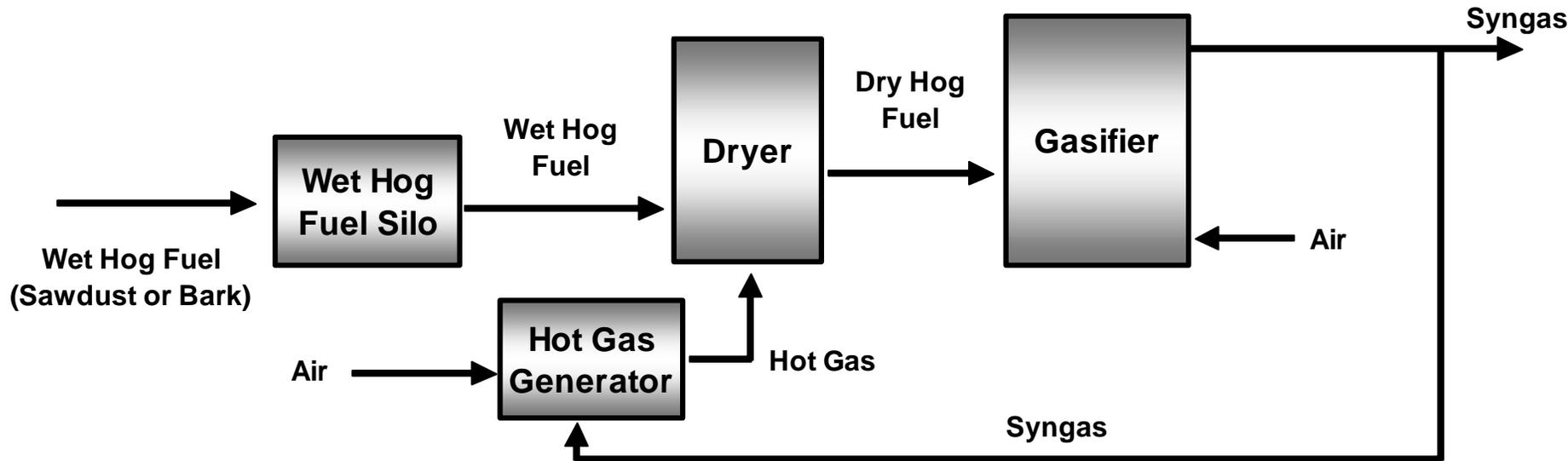


Composition and Heating Value

Component	Composition (dry basis)
CO	15-42%
CH ₄	2-8%
H ₂	10-30%
CO ₂	16-18%
O ₂	<1%
N ₂	As balance
HHV: 3.5 -11.5 MJ/kg (1500 - 5000 Btu/lb)	

Commercial Installations for Lime Kilns

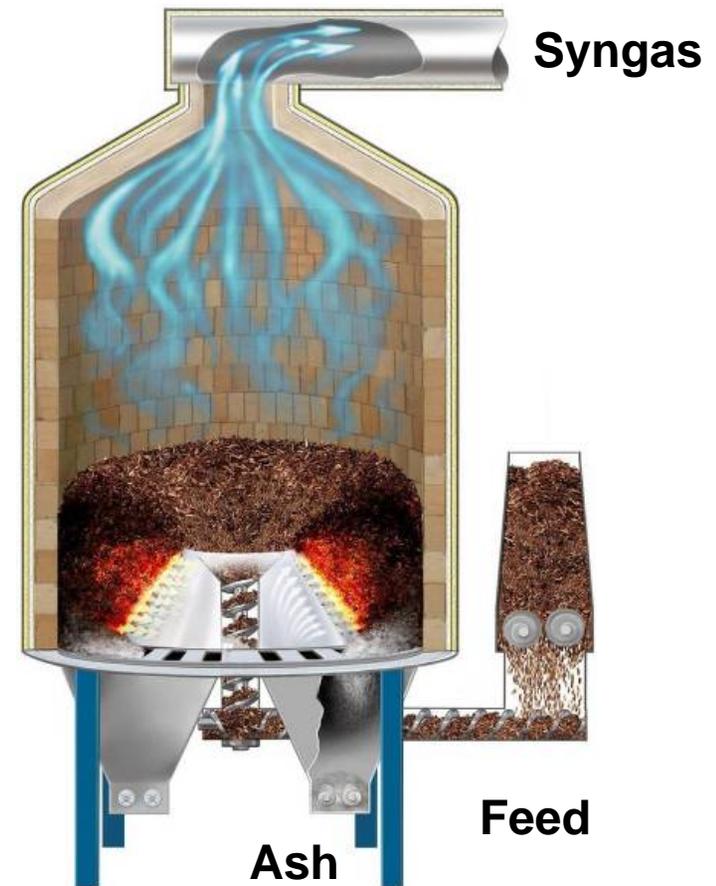
TYPICAL GASIFIER SYSTEM SCHEMATIC



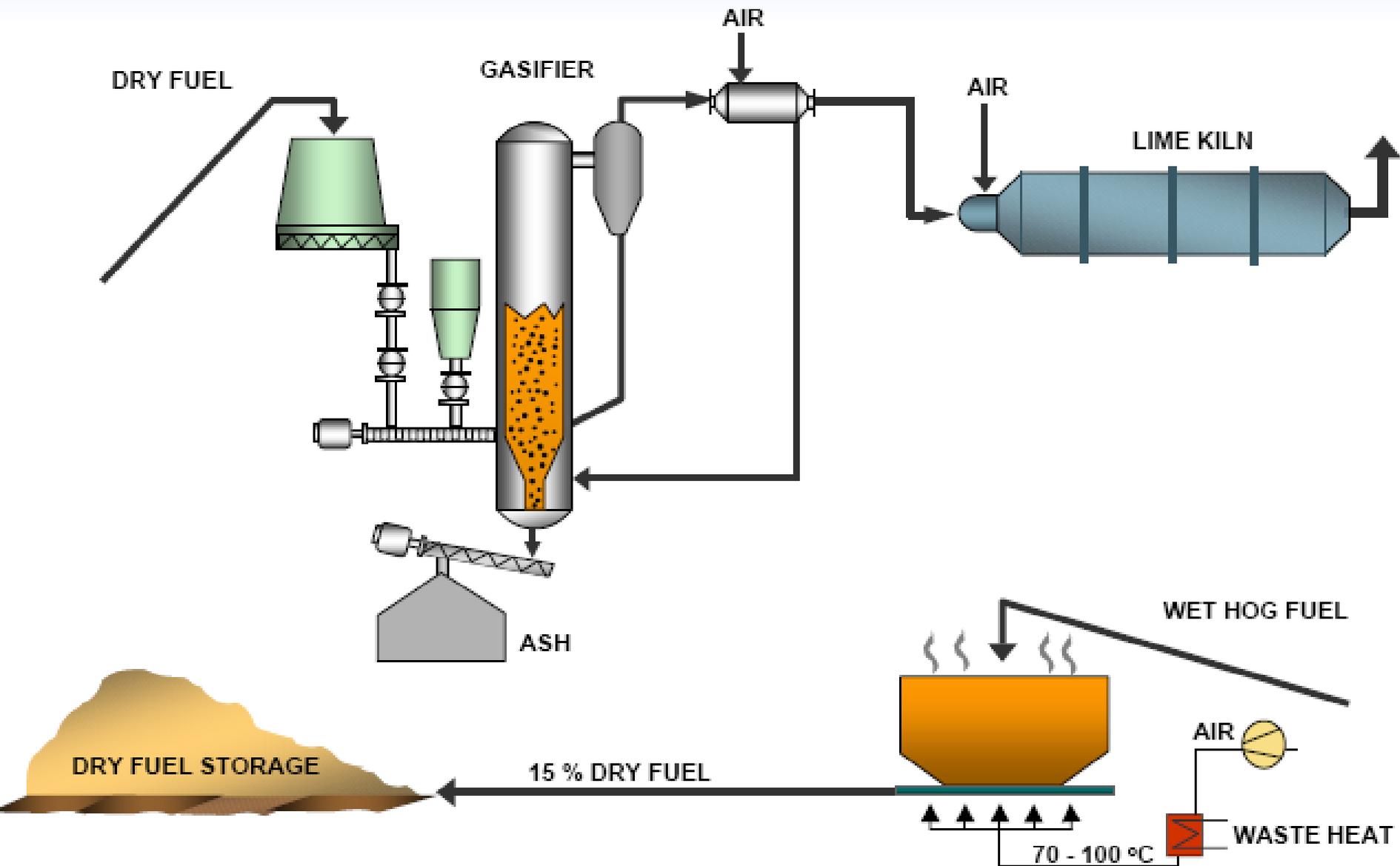
- Sweden, Finland, Portugal – 1980's
- Goal: 100% fuel substitution
- Low availability: dryers and feed systems

Gasification Today

- Number of different suppliers and different types
- Two major classes for lime kiln applications:
 - Fluidized Bed Type Gasifiers:
 - Low Pressure Air-Fed Circulating Fluidized Bed (CFB) Gasifiers
 - Fixed Bed Updraft Type Gasifiers



PULP MILL LIME KILN GASIFIER



New Generation of Gasifiers

- Improved Feed Systems
- Wood Residue Drying
 - Importance: lower the feed moisture \Rightarrow higher syngas exit T, increased HV, reduction in tar condensation on equipment
 - New drying options: to overcome mechanical component failures, fire safety, availability issues experienced in older dryers
 - e.g. low temperature belt dryers

Gasification Pros and Cons

PROS:

- Renewable, Non-Fossil Fuel
- Greenhouse Gas Emission Reduction
- Economic Benefits

CONS:

- Low heating value
- Low availability in the past
- Lower flame T and different T profile
- Possible introduction of NPE's

Summary

- Different process impacts for each fuel
- Petcoke:
 - High heating value and low cost
 - Concerns over high S content
- Gasified Wood Residues, Directly Fired Wood Residues, Bio-oil, Precip. Lignin:
 - Renewable, reduce net CO₂ emissions
 - Lower heating values
- Optimal choice will vary from mill to mill

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