Overview of European torrefaction landscape

Ronald Meijer

EPRI Biomass Torrefaction Workshop
April 13-14, 2011, Pensacola, FL, US
KEMA at a glance

- Established in 1927, Arnhem, the Netherlands
- 2,000 professionals in 18 counties, 600+ in US
- Annual revenues of $350 million

Serving electric utilities’ diverse needs from generation to retail
Covering the entire energy value chain

One company serving the diverse needs of the energy marketplace
KEMA around the globe

- Office locations
- Agents / Business partners
KEMA’s Torrefaction experience

• KEMA has 20 years experience with co-firing of biomass in Europe and since 2003 in US and is involved in torrefaction from the early beginning

• KEMA – as independent consultant - has supported international clients with technical, economical and strategic advice and has hands-on experience by working as a owner’s representative

• KEMA serves as an service provider between torrefaction developers, governmental agencies and utilities and is dedicated in taking torrefaction to the next level for our clients
### Indicative fuel properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Woodchips</th>
<th>Wood pellets</th>
<th>Torrefaction pellets</th>
<th>Charcoal</th>
<th>Coal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture content (% wt)</td>
<td>30 – 45</td>
<td>7 – 10</td>
<td>1 – 5</td>
<td>1 – 5</td>
<td>10 – 15</td>
</tr>
<tr>
<td>Calorific value (MJ/kg)</td>
<td>9 – 12</td>
<td>15 – 16</td>
<td>20 – 24</td>
<td>30 – 32</td>
<td>23 – 28</td>
</tr>
<tr>
<td>Volatiles (% db)</td>
<td>70 – 75</td>
<td>70 – 75</td>
<td>55 – 65</td>
<td>10 – 12</td>
<td>15 – 30</td>
</tr>
<tr>
<td>Bulk density (kg/l)</td>
<td>0.2 – 0.25</td>
<td>0.55 – 0.75</td>
<td>0.75 – 0.85</td>
<td>~ 0.20</td>
<td>0.8 – 0.85</td>
</tr>
<tr>
<td>Volumetric energy density (GJ/m³)</td>
<td>2.0 – 3.0</td>
<td>7.5 – 10.4</td>
<td>15.0 – 18.7</td>
<td>6 – 6.4</td>
<td>18.4 – 23.8</td>
</tr>
<tr>
<td>Dust</td>
<td>Average</td>
<td>Limited</td>
<td>Limited</td>
<td>High</td>
<td>Limited</td>
</tr>
<tr>
<td>Hygroscopic properties</td>
<td>Hydrophilic</td>
<td>Hydrophilic</td>
<td>Hydrophobic</td>
<td>Hydrophobic</td>
<td>Hydrophobic</td>
</tr>
<tr>
<td>Biological degradation</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Milling requirements</td>
<td>Special</td>
<td>Special</td>
<td>Classic</td>
<td>Classic</td>
<td>Classic</td>
</tr>
<tr>
<td>Handling properties</td>
<td>Special</td>
<td>Easy</td>
<td>Easy</td>
<td>Easy</td>
<td>Easy</td>
</tr>
<tr>
<td>Product Consistency</td>
<td>Limited</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Transport cost</td>
<td>High</td>
<td>Average</td>
<td>Low</td>
<td>Average</td>
<td>Low</td>
</tr>
</tbody>
</table>
Van Krevelen diagram of different fuels

Source: ECN
1. Co-milling of biomass with coal
2. Separate milling, injection in pf-lines, combustion in coal burners
3. Separate milling, combustion in dedicated biomass burners
4. Biomass gasification, syngas combusted in furnace boiler
5. Co-milling of torrefied biomass with coal

Each co-firing route has its own (unique) operational requirements and constraints and specific demands on the fuel quality.
The added value of torrefaction

<table>
<thead>
<tr>
<th>Higher co-firing percentages</th>
<th>Torrefied product can be directly milled and co-fired with the coals. Product is dry (&lt; 5%) and has a calorific value of 20 – 24 MJ/kg (8600-10300 BTU/lb). The product is brittle and easily breaks down in small particles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capex savings at the power plant</td>
<td>A smaller mass stream and when pelletized also a smaller volume stream of biomass is needed for the same amount of energy production, which reduces the dimensions of biomass equipment. Further, less biomass equipment (silo’s, dedicated feeding system, biomass mills and burners) is needed.</td>
</tr>
<tr>
<td>Cost savings long distance transport</td>
<td>The volumetric energy density of torrefaction pellets is 16 GJ/m³ compared to 10 GJ/m³ for wood pellets. This implies significant cost savings</td>
</tr>
</tbody>
</table>
Torrefaction technologies

- Oscillating belt reactor
- Moving bed reactor
- Torbed reactor
- Rotary drum reactor
- Screw conveyor reactor
- TurboDryer
- Micro wave reactor
Torrefaction benchmark: technical evaluation

- Evaluation of torrefaction technologies
  - Reactor technologies
  - Heat integration design

- Performance evaluated quantitatively and qualitatively:
  - Energy yield
  - Thermal efficiency
  - Product quality
  - Fuel flexibility
  - Process control
  - Throughput
  - Tar emissions
  - And ....
Technical feasibility

- Spence simulations of co-firing torrefied biomass, impact on plant performance
- Spence simulations of a heat integrated torrefaction plant, mass and energy balance calculations
- Heat integration options of torrefaction (direct or indirect heating)
- Conceptual design and lay out of torrefaction plant
Economic feasibility of torrefaction business case

- Define business case(s)
  - standalone torrefaction plant
  - integrated to power plant
  - compare to wood pellets
  - ........

- Assessment of complete value chain
  - Accumulated cost over the chain
  - Accumulated emissions over the chain
  - CO₂ efficiency

- Sensitivity analysis (Tornado Chart)
  - Top 15 variables determining value
  - Scaling effect on business case
Torrefaction technology

- Most reactor technologies applied for torrefaction are proven in other applications (combustion, drying, gasification etc.)

- Overall thermal efficiency very much depends on heat integration design (direct or indirectly heated)

- Process control is the key for good performance and product quality (residence time, temperature, particle size feed, mixing)

- The key for commercial torrefaction will be the trade-off between economic and technical optimization (e.g. lower energy yield versus higher throughput)
Heat integration options

1. Direct heating by recycling flue gas: efficient heat/mass transfer, loss of product
2. Direct heating by recycling torrefaction gas: efficient heat/mass transfer, tar formation
3. Direct or indirect heating by recycling steam: risk on carbonization
The product of torrefaction (1/2)

<table>
<thead>
<tr>
<th>Storage and handling</th>
<th>Industrial scale experience and validated data is needed on handling, storage (hydrophobic), milling, explosion risk, dust and odor emissions, combustion properties (burn-out, reactivity) of the product</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pelletization</td>
<td>Low torrefaction temperatures (260 - 300°C, 500-570 F) lead to best results (due to lignin as natural binder), different additives are being explored and used (e.g. glycerin). Effects on product properties not yet known</td>
</tr>
<tr>
<td>Combustion behaviour</td>
<td>Quick devolatilization, a slightly longer burn-out.</td>
</tr>
</tbody>
</table>
## The product of torrefaction (2/2)

### Sustainability
Sustainability is an important topic for the EU biomass market. CEN 383 group is working out the EU policy. CO₂ balance over the value chain will be the most important criteria. Thus carbon footprint of torrefaction installation as low as possible.

### Standardization
Market needs standardization of product quality and specifications. Currently, large differences in product quality

### Price
Most utilities are considering a wood pellet price of 120 – 130 EUR/ton CIF ARA as reference for the price of torrefied wood pellets plus a correction for the energy content of the product. This leads to a product price of about 150 – 190 EUR/ton. However, without subsidies, the coal price serves as reference + CO₂ credit price + savings on power plant = 100 – 120 EUR/ton
## EU market drivers of torrefaction

<table>
<thead>
<tr>
<th>Financial incentives</th>
<th>Renewable production subsidies, CO\textsubscript{2} credits, cost savings at the power plant, cost-effective method to co-fire biomass, lower transport cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical incentives</td>
<td>Security of supply of fossil fuels, higher co-firing percentage possible, no dedicated biomass equipment (like hammer mills) needed, reduce cost of entrained flow gasification</td>
</tr>
<tr>
<td>Environmental incentives</td>
<td>CO\textsubscript{2} emissions, renewable energy targets, making waste stream (agricultural residues) available for energy production, sustainability criteria in Europe</td>
</tr>
<tr>
<td>Strategic incentives</td>
<td>Secure biomass supply by taking position upstream, cost-effective method to comply with energy policy, life-time extension of aging assets</td>
</tr>
</tbody>
</table>
Strategy /position of European coal-fired pp

- Keep the asset operational, but risk increasing environmental fees (renewable energy targets, CO₂ emission credits)

- Decommission asset before economical lifetime, representing a huge capital loss and possibly a shortage of base load electricity production

- Repower the asset to a 100% biomass plant, which will require significant investments and brings along considerable (operational) risks

- Keep asset operational by co-firing biomass, which also requires significant investments in biomass pre-treatment, storage and handling equipment
# Market potential of torrefied biomass in EU

<table>
<thead>
<tr>
<th>Market segment</th>
<th>Conversion process</th>
<th>Conversion technology</th>
<th>State-of-the-art biofuel</th>
<th>Pre-treatment requirements</th>
<th>Advantages of torrefaction</th>
<th>Market potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large-scale Power production</td>
<td>Co-firing</td>
<td>Coal-fired boilers</td>
<td>Wood pellets</td>
<td>High</td>
<td>Process with the coal, higher co-firing rates</td>
<td>High</td>
</tr>
<tr>
<td>(Co)gasification</td>
<td>(Co)gasification</td>
<td>Entrained flow gasifiers</td>
<td>Wood pellets</td>
<td>Very high, due to particle size</td>
<td>Size reduction, fluidization, C/H/O ratio, very dry</td>
<td>Limited</td>
</tr>
<tr>
<td>Stand-alone Combustion (&gt;20 MWe)</td>
<td>CFB boilers</td>
<td>Wood chips</td>
<td></td>
<td>Moderate</td>
<td>Limited, relatively expensive</td>
<td>Small</td>
</tr>
<tr>
<td>Industrial heating</td>
<td>Combustion</td>
<td>Blast furnaces</td>
<td>none</td>
<td>Moderate</td>
<td>Handling, C/H/O ratio, energy content</td>
<td>High</td>
</tr>
<tr>
<td>Residential/ District heating</td>
<td>Combustion</td>
<td>Stoves</td>
<td>Wood pellets</td>
<td>High, decentralized</td>
<td>Transport savings</td>
<td>High</td>
</tr>
</tbody>
</table>
## European torrefaction initiatives

<table>
<thead>
<tr>
<th>Developer</th>
<th>Technology</th>
<th>T. Supplier</th>
<th>Location(s)</th>
<th>Production capacity (t/a)</th>
<th>Starting operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Topell Energy B.V. (NL)</td>
<td>Torbed</td>
<td>Torftech Inc (UK)</td>
<td>Duiven (NL)</td>
<td>60,000</td>
<td>Q4 2010</td>
</tr>
<tr>
<td>Stramproy Green Investment B.V. (NL) / 4Energy Invest (BE)</td>
<td>Oscillating belt reactor</td>
<td>Stramproy Group (NL)</td>
<td>Steenwijk (NL), Amel (BE)</td>
<td>45,000 / 38,000</td>
<td>Q3 2010</td>
</tr>
<tr>
<td>Torr-Coal B.V. (NL)</td>
<td>Rotary drum</td>
<td>Torr-Coal technology B.V. (NL)</td>
<td>Dilsen-Stokkem (BE)</td>
<td>35,000</td>
<td>Q3 2010</td>
</tr>
<tr>
<td>Lantec Group (SP)</td>
<td>Moving bed</td>
<td>Thermya (FR)</td>
<td>San Sebastian (SP)</td>
<td>20,000</td>
<td>2011</td>
</tr>
<tr>
<td>Vattenfall/ Nuon (NL)</td>
<td>Moving bed</td>
<td>ECN (NL)</td>
<td>Delfzijl (?)</td>
<td>20,000 (?)</td>
<td>Unknown</td>
</tr>
<tr>
<td>FoxCoal B.V. (NL)</td>
<td>Screw conveyor</td>
<td>FoxCoal B.V. (NL)</td>
<td>Winschoten (NL)</td>
<td>35,000</td>
<td>2012</td>
</tr>
<tr>
<td>BioLake B.V. (NL)</td>
<td>Screw conveyor</td>
<td>Unknown</td>
<td>Eastern Europe</td>
<td>5,000 – 10,000</td>
<td>Q4 2010 ?</td>
</tr>
<tr>
<td>BioEndev (SE) / ETPC (SE)</td>
<td>Rotary drum</td>
<td>Unknown</td>
<td>Ö-vik (SE)</td>
<td>25,000 – 30,000</td>
<td>2011/ 2012</td>
</tr>
<tr>
<td>EBES AG (AT)</td>
<td>Rotary drum</td>
<td>Andritz (AT)</td>
<td>Frohnleiten (Austria)</td>
<td>10,000</td>
<td>2011</td>
</tr>
<tr>
<td>Atmosclear SA (CH)</td>
<td>Rotary drum</td>
<td>Airless Systems (UK)</td>
<td>Rezekne (Latvia), New Zealand, US</td>
<td>50,000</td>
<td>Q4 2010</td>
</tr>
</tbody>
</table>

* This is not the full list and figures are based on statements of developers
European torrefaction outlook

- Increasing demand for larger volumes of affordable, reliable and sustainable co-firing fuel, that can meet EU sustainability criteria.

- Several Torrefaction demo plants in Europe, have to prove they are able to continuously produce large volumes of high quality torrefied product (specifications of off-takers)

- As a next step multiple commercial sized (100 kton/yr) torrefaction plants will be erected for supply to Europe, especially in regions where biomass is widely available and and relatively cheap
  - Russia, Belarus, Ukraine, Slovakia
  - Brazil, Africa, Canada, US
Latest on torrefaction initiatives in EU

- Topell Energy commissioned and in operation (8 t/h)

- Stramproy Green Investment has stopped production due to operational problems. Stramproy delivered first batch to Essent/RWE and the product did not (yet) meet the requirements

- Torr-Coal has started up demo plant, but is not operating at full capacity. Delivers product as powder to utility in Belgium
First batch of Cool Coal (Stramproy Green Energy)

Amer power plant of Essent, 29 July, 2010
Torrefaction demo plant of Topell Energy (60 kton/yr)
Pilot plant measurements at CMI-NESA (Multiple hearth furnace)
### The major technical challenges of torrefaction

#### Feedstock flexibility
Currently torrefaction technologies are mainly processing wood chips for a narrow bandwidth of particle size. Agricultural residues are still a challenge, because it ignites easily, has a low bulk density and has long fibers.

#### Process validation
Although experience has been gained with pilot plant testing, real operational data will reveal the performance of the torrefaction process. Important is the trade-off between energy yield, product quality and production cost.

#### Product validation
Although the pilot plant test results are promising, the product needs to be validated by large co-firing trials. Are torrefaction suppliers able to commercially provide a product which meets the specifications of an utility? And is the product really sustainable?
The major business challenges of torrefaction

<table>
<thead>
<tr>
<th>Financing</th>
<th>Most torrefaction developers are small companies with a limited financial base. Convincing investors to finance the necessary R&amp;D and up-scaling efforts is a real challenge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Market maturity</td>
<td>One or more torrefaction concept will emerge out of a large variety of technologies and initiatives. But have torrefaction suppliers enough development power to optimize and scale-up their torrefaction concept? A product standardization is needed to make the market more transparent and reliable</td>
</tr>
<tr>
<td>Availability of product</td>
<td>The demand is significantly higher than the supply. Torrefaction suppliers are facing the challenge to scale-up their first commercial demonstration plants in a rapid pace</td>
</tr>
</tbody>
</table>
Future of co-firing and repowering in Europe

- Significant investments needed to enable using of a more expensive fuel...
- Low incentives from current CO₂ price
- Limited or no real political and financial incentives in many (EU) countries
- Biomass suppliers suffer from uncertainties
- Biomass politically not fully undisputed
Future of co-firing and repowering in Europe

• However…
  – most large scale alternatives i.e. wind power are more expensive (EUR/MWh)
  – significant renewable targets to be achieved relatively shortly (2020)
  – wind power comes with high investment costs and complex permitting issues
  – existing coal fired unit owners are keen to find alternatives
  – co-firing and repowering could be the short term option for politics to meet renewable targets
2011 Year of Torrefaction !?

Profitable
Sustainable
Reliable
Co-firing

Experience you can trust.
Contact

Ronald Meijer
Managing Principal clean Fossil Power
KEMA Nederland BV
Arnhem, Netherlands
Phone +31 26 356 24 34
Fax +31 26 351 36 83
Email ronald.meijer@kema.com
Website www.kema.com
Contact

Dick Bratcher
Senior Principal, Power Generation & Renewables
KEMA, Inc. 155 Grand Avenue, Suite 500
Oakland, CA 94612 USA
T +1 510 891 0446
M +1 510 338 8062
dick.bratcher@kema.com
www.kema.com
KEMA as partner in torrefaction business

**Torrefaction opportunities**
- Torrefaction strategy: buy technology or product
- Investment decisions, business case
- Selection of torrefaction technology that best fits clients business
- Selection of torrefaction supplier
- Selection of EPC contractor
- Process validation
- Product validation
- Biomass certification
- Product standardization

**KEMA services**
- Support business strategy
- Torrefaction technology benchmark
- Evaluation of initiatives and projects
- Techno-economic feasibility study
- Evaluation of business case
- Contractor survey, Coordination of tendering phase
- Pilot plant testing, Factory acceptance test
- Small scale combustion tests
- Coordination of co-firing trials
- Sustainability of total value chain

**Cooperation**