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Grasmo Steam Explosion Pellet Plant - built in 2003

Verification program with Vattenfall, 4300 tons at Reuter West, Berlin

Thunder Bay GS – world first full conversion to Advanced Wood Pellets

Conversion of coal power plants to Advanced Wood Pellets

WPAC, Halifax
November 3-5, 2015
by Arne Erik Kristiansen

Handled as coal thru the value chain
Market positioning of pellets

**White pellets**
- New installation or major modification required
  - Residential Stoves
  - Heating/Steam market: Pellet burners

**Advanced wood pellets**
- Minor modification
  - Coal Power Stations /Industry

**Heating and Residential market**
- Smart

**Industrial market**
- New and dispatchable
Arbapellets - Advanced Wood Pellet (AWP) – key advantages

**Arbapellets vs. White Pellets**
- Water resistant
- “Dust free” – lower dust explosion risk
- 40% lower volume - same energy content
- Lower handling, storage and transport cost
- Outstanding mechanical properties

**Arbapellets vs. Coal**
- Energy value and other properties close to coal
- Transport, storage, handling, milling and combustion with same equipment
- Coal replacement up to 100% with minor modification (white pellets up to 5%)
- Reduction of CO₂ emissions by 100%

*Water resistance represents a key advantage*

*Arbapellets favorably positioned compared with alternative technologies*

Source: Arbaflame
Arbapellets® - the original steam explosion pellets

- Production since 2003 in Grasmo Plant, Norway
  - Accumulated production 120,000 tons
  - Capacity ~ 25,000 tons/year

- Patented Production Process
  - Domestic heating market
  - Reduction material for smelters
  - Since 2010 – focus on coal replacement

- Verification program
  - Test volumes for coal plants
  - Fine-tuning of production process and product properties
  - Test of different raw material

⇒ Long, unique experience from producing and testing
⇒ Industrial scale-up by additional units
## Fuel comparison

<table>
<thead>
<tr>
<th>Properties</th>
<th>Wood chips</th>
<th>White pellets</th>
<th>Arbapells</th>
<th>Torrefied pellets</th>
<th>Hard Coal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk density</td>
<td>300 kg/m³</td>
<td>650 kg/m³</td>
<td></td>
<td>750 kg/m³</td>
<td>850 kg/m³</td>
</tr>
<tr>
<td>Energy density</td>
<td>3 GJ/m³</td>
<td>11 GJ/m³</td>
<td>15-16 GJ/m³</td>
<td>17 GJ/m³</td>
<td>21 GJ/m³</td>
</tr>
<tr>
<td>Water resistant</td>
<td></td>
<td>Poor</td>
<td>Very good</td>
<td>Good ?</td>
<td>Very good</td>
</tr>
<tr>
<td>Durability</td>
<td>n.a</td>
<td>Good</td>
<td>Very good</td>
<td>Good ?</td>
<td></td>
</tr>
<tr>
<td>Binder</td>
<td></td>
<td>No</td>
<td>No</td>
<td>Binder needed</td>
<td></td>
</tr>
<tr>
<td>Mass loss</td>
<td>n.a</td>
<td></td>
<td>10 – 15 %</td>
<td>&gt; 35 %</td>
<td></td>
</tr>
<tr>
<td>Co-firing rate</td>
<td>3-5%</td>
<td>5-8%</td>
<td>&gt; 100% proven</td>
<td>?</td>
<td>n.a</td>
</tr>
<tr>
<td>Millability</td>
<td></td>
<td>Poor</td>
<td>Good</td>
<td>Good ?</td>
<td>Very good</td>
</tr>
<tr>
<td>Dust % delivered</td>
<td>High ~3-7 %</td>
<td></td>
<td>Low &lt; 1%</td>
<td>&gt; 5-10% ?</td>
<td></td>
</tr>
<tr>
<td>Product Approval</td>
<td></td>
<td></td>
<td>Yes</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>by Utility Testing</td>
<td></td>
<td></td>
<td></td>
<td>Pilot/demo plants</td>
<td></td>
</tr>
<tr>
<td>Technical Dvlp.</td>
<td>Mature (20 years)</td>
<td>READY TO BUILD</td>
<td></td>
<td>(1-2 years)</td>
<td></td>
</tr>
<tr>
<td>Status operation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Arbaflame
Handled as coal throughout the supply chain with only minor modification

Vattenfall quote: “Co-combustion lowest cost and capex option to reduce CO₂ in Europe”
Full scale tests performed with Arbapellets at > 8 coal fired power stations

2010
Uppsala, Sweden
300 MW CHP

2010
Uskmouth, Wales
330 MW power station

2011
Reuter West, Berlin Germany
2 * 300 MW power station
Co-firing 20% to 50%

2012
Buggenum, Holland
Gassification 250 MW
Co-firing 50 and 70%

2012
Amager, Denmark
250 MW CHP

2013
Tilbury, UK
900 MW power station

2013 & 2014
Thunder Bay, Canada
312 MW power station
Dedicated 100 % capacity

2014
Hanasasari, Finland
200 MW power station

Source: Arbaflame

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Ontario Power Generation, Canada
– converted two coal plants to 100% biomass

Atikokan GS
- 205 MWe – White Pellets
- Project duration
  - 18 months (9 month outage)
- Conversion Capex - Major
  - $ 170 M (€ 600/KW)
  - New fuel receiving, storage silos
  - New burners and modification of mills
- Supplier – peaking plant
  - Two local suppliers

Thunder Bay GS Unit 3
- 150 MWe – Advanced Biomass
- Project duration
  - 7 months (2 month outage)
- Conversion Capex - Minor
  - $ 5 M (€ 25/KW)
  - Outdoor fuel storage
  - Minor changes (safety and dust suppression)
- Supplier – peaking plant
  - Arbaflame

Source: Ontario Power Generation
Arbaflame - supplier to the world’s first conversion to advanced wood pellets

Thunder Bay Plant operating on Arbapellets

Arbapellets in winter storage

World’s first commercial contract with advanced wood pellets (AWP) for 100% replacement of coal based on:

2013
- May - Access to results from Vattenfall & Arbaflame verification program shared with Ontario Power Generation
- June  - Delivery of 20 tons for external lab testing
- Sept  - Delivery of 1200 tons for full-scale verification

2014
- July  - Arbaflame selected as supplier for first commercial volume
- Sept  - First delivery arrived Thunder Bay for storage

2015
- Jan – Commercial operation
Upgrade biomass to AWP to achieve high co-firing rates and reduced cost

Fuel cost comparison White and Advanced Wood Pellets

Eur/MWh fuel (indicative)

Source: Vattenfall & own analysis
# Coal to Biomass – Conversion 10 to 100 %
## - White vs Advanced Wood Pellets

### Case Example

<table>
<thead>
<tr>
<th>Coal Plant - 500 MW</th>
<th>White pellets</th>
<th>ArbaPellets</th>
<th>ArbaPellets</th>
<th>ArbaPellets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conversion level</td>
<td></td>
<td>10 %</td>
<td>20 %</td>
<td>100 %</td>
</tr>
<tr>
<td>10 %</td>
<td>New receiving system</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>20 %</td>
<td>New covered storage</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>100 %</td>
<td>New handling system</td>
<td>-</td>
<td>Minor retrofit</td>
<td>Minor retrofit</td>
</tr>
<tr>
<td>Type of modification</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Receiving</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Storage</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Handling</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pulverizer</td>
<td>Co-milling</td>
<td>New or modified mills</td>
<td>-</td>
<td>Modify mills ?</td>
</tr>
<tr>
<td>BoP</td>
<td>Co-firing</td>
<td>New or modified burners</td>
<td>Site specific</td>
<td>Site specific</td>
</tr>
<tr>
<td>Safety systems</td>
<td>Minor</td>
<td>Extensive</td>
<td>Minor</td>
<td>Minor</td>
</tr>
<tr>
<td>Downtime</td>
<td>~ 3 mths</td>
<td>6 to 12 mths</td>
<td>12 to 18 mths</td>
<td>1 - 3 mths</td>
</tr>
<tr>
<td>Capex * ) €/KW</td>
<td>50 - 100</td>
<td>100 - 400</td>
<td>200 - 500</td>
<td>0 - 5</td>
</tr>
<tr>
<td>Capex - € M</td>
<td>38</td>
<td>150</td>
<td>200</td>
<td>3</td>
</tr>
</tbody>
</table>

*) from DECC report, OPG cost at Thunder Bay, project cases

**MAJOR MODIFICATION**

**MINOR MODIFICATION**

Source: Arbaflame
Replacement of coal – 20 % conversion

Major value creation with Advanced Wood Pellets

**Case Example**

<table>
<thead>
<tr>
<th>Coal Plant - 500 MW</th>
<th>White pellets</th>
<th>ArbaPellets</th>
<th>SAVINGS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Conversion level</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20 %</td>
<td>20 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GWhe from bio 1)</td>
<td>600</td>
<td>600</td>
<td></td>
</tr>
<tr>
<td>kWh/Kg</td>
<td>4,8</td>
<td>5,4</td>
<td></td>
</tr>
<tr>
<td>Pellet tons</td>
<td>300 000</td>
<td>265 000</td>
<td></td>
</tr>
<tr>
<td>Fuel cost pellets € per MW</td>
<td>31</td>
<td>34</td>
<td></td>
</tr>
<tr>
<td>Capex 2) €/KW</td>
<td>300</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Capex € M</td>
<td>150</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Fuel cost pellets €M/year</td>
<td>44</td>
<td>49</td>
<td></td>
</tr>
<tr>
<td>Improved efficiency €M/year</td>
<td></td>
<td></td>
<td>-4</td>
</tr>
<tr>
<td>Local handling, storage €M/year</td>
<td>3</td>
<td>2</td>
<td>not incl. here</td>
</tr>
<tr>
<td>Capital cost - annunity 3) €M/year</td>
<td>24</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total cost - bio part €M/year</strong></td>
<td>72</td>
<td>52</td>
<td>€ 20 M</td>
</tr>
</tbody>
</table>

1) 6 000 hrs, efficiency 44 %
2) from DECC report, OPG cost at Thunder Bay, project cases
3) Annunity 10%, 7 year

Source: Arbaflame
**AWP – cost competitive for peak load**

**LCOE/MWhe - Base and 20% peak**

1) Ave cost 20% co-firing
2) Fixed cost for gas mgmt capacity can be very high if peak only
4) same peak capacity require 2,5 times capex

Source: Arbaflame
Advanced wood pellets
– cost competitive, low capex, CO2 reduction, job creation

Source: Arbaflame
AWP – cost competitive for peak load

AWP is the green dispatchable power solution
- Low cost and capex
- Easy to ramp-up

How secure peak demand?

Source: Arbaflame
Brownfield plant with biomass infrastructure
- Production capacity of 200,000 tons/year
- at Follum former Norske Skog paper mill site
- Stable feedstock supply from certified forest
- Final Investment Decision in 4Q 2015

Short distance to European utilities
- Short distance to port – 70 km
- Maritime distance 1-3 days
- Direct access to customers with small and large vessels
  - «FOB-port same as CIF ARA»
  - Buffer volume/Storage option

ArbaFollum Plant, Hønefoss Norway

Partners
- Arbaflame - technology provider
- Viken Skog - site owner and feedstock supplier
  - owned by > 10,000 forest owners
- Statskog - Norwegian State forest company
Ontario – large opportunity next door

Slow phase-out of coal creates a huge market for Forestry and biomass in Canada. Arbaflame will focus on this opportunity with Advanced Wood Pellets.
**Advanced Wood Pellet – A game changer**

**Proof of concept of technology, product and market**

Full replacement of coal is **now possible** with only minor modifications

AWP has **lower fuel cost** than white pellets including modification cost

AWP is a solution for using existing coal power plants and grid for:
- green base-load power and green flexible dispatchable power

**Commercialization**

Secure first off-take contracts – ongoing discussions

Secure equity funding for expansion of Arbaflame

Co-build first 2-3 AWP plants
- Build a first scale-up Arba Follum plant in Norway
- thereafter co-build additional plants and technology licensing

**Strategic partnerships**
- Global investment fund
- Market entry Asia
- Strong feedstock partners
Advanced Wood Pellet – A game changer

Challenges

- Proof of concept? Technology, product and market is now proven
- Low cost on coal and carbon Policy makers forced to increase cost of carbon?
- Build up of security of supply Soon take-off – stepwise build-up Also retrofit of conventional plants

Opportunities

- Low(est) cost and capex options for green dispatchable power
- Use of existing coal power plants and grid
- Easy to ramp-up - both stepwise co-firing, dispatchable and base load
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