Wastewater innovation in Denmark
Water technology alliance

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WHY ARE WE HERE?
Knowledge sharing & collaboration

In California and in Denmark
drivers in a nutshell

- Regulation
- Environmental Regulation
- Water Sector Regulation
- Ltd Companies
- Benchmarking
- Efficiency 2%

Water Vison
Energy & CO2 Neutrality

Business Mindset
Environment
## Discharge Standards – Development

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>1960</th>
<th>1970-80</th>
<th>1990</th>
<th>2016 (sensitive areas)</th>
<th>EC Standards (1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOD$_5$</td>
<td>mg/l</td>
<td>150</td>
<td>25</td>
<td>15</td>
<td>10</td>
<td>25</td>
</tr>
<tr>
<td>Total N</td>
<td>mg/l</td>
<td>-</td>
<td>-</td>
<td>8</td>
<td>8</td>
<td>15</td>
</tr>
<tr>
<td>Total P</td>
<td>mg/l</td>
<td>-</td>
<td>-</td>
<td>1.5</td>
<td>0.4</td>
<td>1</td>
</tr>
<tr>
<td>Treatment</td>
<td></td>
<td>M</td>
<td>MB</td>
<td>MBNP</td>
<td>MBNPS</td>
<td></td>
</tr>
</tbody>
</table>

Legend:
- M = Mechanical
- MB = Mechanical-Biological
- MBNP = Mechanical-Biological-Nitrogen-Phosphorus removal
- MBNPS = Mechanical-Biological-Nitrogen-Phosphorus removal and sand filtration


Tax Payment to Government on all three parameters
Regulation by "pollution" tax

<table>
<thead>
<tr>
<th>Tax Rates – Pollution Discharge</th>
<th>Units</th>
<th>2016</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total N</td>
<td>$/lb</td>
<td>2,25</td>
</tr>
<tr>
<td>Total P</td>
<td>$/lb</td>
<td>12,4</td>
</tr>
<tr>
<td>BOD$_5$</td>
<td>$/lb</td>
<td>1,25</td>
</tr>
</tbody>
</table>

1 USD = 6,63 DKK
CASE
Marselisborg WWTP Aarhus Water, Denmark

- 200,000 PE (1 PE = 0.060 kg BOD/day (= 0.13 lbs/day))
- Designed in the 80’s. Nutrient demands in the 90’s.
1990 Challenge: Optimization

- Increase the efficiency & capacity of the WWTP, oh and…

- Reduce effluent values oh and…

- without any major investments in the treatment plants themselves

- Open systems configurable by Aarhus Water’s own staff
Plant Layout
Marselisborg WWTP - 220,000 PE

- Sand filters
- Final dewatering
- Biogas utilization
- Digesters
- Secondary sedimentation
- Process tanks N/DN
- Sludge thickening Pre-dewatering
- Sand filters
- Storm Water Holding tanks
- Primary Sedimentation
- Secondary Sedimentation
- Sludge liquor treatment Anammox
- Secondary Sedimentation
## Marselisborg WWTP Compliance with effluent standards

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Standard</th>
<th>Average</th>
<th>Control Value, C</th>
<th>Compliance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total N</td>
<td>mg/l</td>
<td>8</td>
<td>5.59</td>
<td>4.86</td>
<td>Yes</td>
</tr>
<tr>
<td>Total P</td>
<td>mg/l</td>
<td>0.8</td>
<td>0.25</td>
<td>0.22</td>
<td>Yes</td>
</tr>
<tr>
<td>Total P</td>
<td>kg/d</td>
<td>20.8</td>
<td>7.21</td>
<td>6.46</td>
<td>Yes</td>
</tr>
<tr>
<td>BI5&lt;sub&gt;mod&lt;/sub&gt;</td>
<td>mg/l</td>
<td>15</td>
<td>2.14</td>
<td>2.47</td>
<td>Yes</td>
</tr>
<tr>
<td>COD</td>
<td>mg/l</td>
<td>75</td>
<td>24.19</td>
<td>21.75</td>
<td>Yes</td>
</tr>
<tr>
<td>SS</td>
<td>mg/l</td>
<td>20</td>
<td>3.01</td>
<td>3.35</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Number of samples: 24
Marselisborg WWTP  
Capacity and loadings 2015

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Capacity</th>
<th>Loading 2015</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average</td>
<td>Average</td>
</tr>
<tr>
<td>Flow</td>
<td>MGD</td>
<td>6,8</td>
</tr>
<tr>
<td>BOD5</td>
<td>[lb/d]</td>
<td>26,675</td>
</tr>
<tr>
<td>Total N</td>
<td>[lb/d]</td>
<td>3,417</td>
</tr>
<tr>
<td>Total P</td>
<td>[lb/d]</td>
<td>943</td>
</tr>
<tr>
<td>$PE_{BOD}$</td>
<td>á 60 g BOD/pxd</td>
<td>200,000</td>
</tr>
</tbody>
</table>

Additional loading to the WWTP:
(1) Septic sludge to inlet = 20-30,000 PE
(2) Reject water from sludge treatment = 15-17,000 PE

PE

Energy self-sufficiency - electricity

Marselisborg WWTP - Self-sufficiency electricity production [%]

- 2012: 120%
- 2013: 128%
- 2014: 131%
- 2015: 121%
- 2016: 153%
## Marselisborg WWTP


<table>
<thead>
<tr>
<th>Energy Self-sufficiency</th>
<th>Net energy production</th>
<th>Energy self sufficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity, year to day</td>
<td>147 %</td>
<td>147 %</td>
</tr>
<tr>
<td>Heat, year to day</td>
<td>193 %</td>
<td></td>
</tr>
<tr>
<td>Energy in total, year to day</td>
<td>169 %</td>
<td>233 %</td>
</tr>
</tbody>
</table>

*Net energy production = Production / Consumption*

*Energy self sufficiency = Sold / Bought*
Solutions

1. Process Optimization
   - Biological Nitrogen and Phosphorus removal
   - Clarifier control (increased hydraulic capacity during rain)
   - Sensors and VFDs (integrated real time process control)

2. Component Optimization
   - Turboblowers
   - Gasengines (CHPs)
   - Fine bubble diffusers / mixers

3. New Processes
   - Simultaneous Nitrification/Denitrification
   - Sidestream Hydrolysis/Bio-P
   - Sidestream De-Ammonification
   - Mainstream Nitrite-shunt
   - Mainstream De-Ammonification
# Results from 1st round Process Optimization

## Economic results: Process Optimization - Municipality of Aarhus

<table>
<thead>
<tr>
<th>Economic results: Process Optimization - Municipality of Aarhus</th>
<th>Unit</th>
<th>Marselis</th>
<th>Egaa</th>
<th>Viby</th>
<th>Aaby</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>WWTP size</td>
<td>PE</td>
<td>200,000</td>
<td>120,000</td>
<td>83,000</td>
<td>84,000</td>
<td>487,000</td>
</tr>
<tr>
<td>Reduction of use of resources - energy and chemicals</td>
<td>EUR/year</td>
<td>73,000</td>
<td>31,000</td>
<td>40,000</td>
<td>132,000</td>
<td>276,000</td>
</tr>
<tr>
<td>Reduced effluent values - lower effluent tax</td>
<td>EUR/year</td>
<td>114,000</td>
<td>19,000</td>
<td>27,000</td>
<td>2,000</td>
<td>162,000</td>
</tr>
<tr>
<td>Increased capacity - depreciation time 25 years</td>
<td>EUR/year</td>
<td>54,000</td>
<td>50,000</td>
<td>132,000</td>
<td>27,000</td>
<td>263,000</td>
</tr>
<tr>
<td>Total</td>
<td>EUR/year</td>
<td>241,000</td>
<td>100,000</td>
<td>199,000</td>
<td>161,000</td>
<td>701,000</td>
</tr>
</tbody>
</table>

## Return of investment

<table>
<thead>
<tr>
<th>Return of investment</th>
<th>Years</th>
<th>1.0</th>
<th>1.5</th>
<th>1.6</th>
<th>0.9</th>
<th>1.2</th>
</tr>
</thead>
</table>
Side-stream treatment of centrate

- Installed and running: 2015
- Flow, max. 15 m³/h
- Average daily flow 280 m³/d
- Ammonium load, average 250 kg/d

- DEMON Plant design data (existing tanks):
  - Equalizing tank 100 m³
  - Process volume (Process tank 1+2) 280 m³
  - Sedimentation tank 5.2 m²

Results:
- Removal efficiency (NH₄-N) > 85%
- Energy consumption ~1,3 kWh/kg NH₄-N removed
- Total N in effluent reduced with approx. 2 mg/l
- Reduced wastewater tax 600,000 DKK/year
Processes for Nitrogen Removal

Nitrification

\[ \text{NH}_4^+ \rightarrow \text{NO}_2^- \rightarrow \text{NO}_3^- \rightarrow \text{O}_2 \]

\[ \text{O}_2 \rightarrow \text{NOB} \]

Denitrification

\[ \text{N}_2 \rightarrow \text{N}_2\text{O} \rightarrow \text{NO} \rightarrow \text{O}_2 \]

\[ \text{O}_2 \rightarrow \text{AOB/DEN} \]

ANAMMOX

\[ \text{NH}_4^+ \rightarrow \text{NO}_2^- \rightarrow \text{NH}_4^+ \]

De-Ammonification
Standard platform for process control and daily operation

- External modeling software (well fields, distribution- and drainage networks, wastewater treatment plants…)
- Other systems (Historians, Labs., Asset management, Meteorology, …) and manual input

**DIMS.CORE**

- SCADA/PLC (OPC servers) Sensors/actuators
- Measurements Set-points
- Results incl. Set-points
- Data Validation, Signal Filters, Aggregation, Visualisation, Reporting
- Validated data
- Software sensors, Process Alarms, Controllers, Models
MARSELISBORG REWATER
- An Open Invitation

MARSELISBORG REWATER
INNOVATION STRATEGY
October 9th to 15th