Ammonia Recovery Process

Cost Benefits to the Operation of a Typical Wastewater Treatment Plant

BioWin® Model Analysis

Presented By:

ThermoEnergy Corporation
Executive Summary

Potential capital cost reductions have been estimated as at least a factor of five with the Ammonia Recovery Process for equivalent ammonia reduction relative to biological methods. Substantial operating cost and energy savings have also been estimated, and this study was undertaken to improve those estimates. The complexity of the municipal wastewater process dictates that a simulation model of the process be used for accurate estimation of their operation. BioWin is the industry standard simulation software and has been used previously to model operations of New York City and other major municipal plants.

Generic models of the two major classes of nutrient reduction technology, single sludge and two sludge, were adapted to provide similar operation to those of New York City for the single sludge category and the Blue Plains plant of WASA for the two sludge category. Sensitivity analyses indicate that the following table reasonably estimates the expected benefits of the Ammonia Recovery Process for each category.

<table>
<thead>
<tr>
<th>Bio Win Model Results</th>
<th>Single Sludge Plant</th>
<th>Two-Sludge Plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methanol Reduction</td>
<td>38%</td>
<td>19%</td>
</tr>
<tr>
<td>Alkalinity Reduction</td>
<td>10%</td>
<td>13%</td>
</tr>
<tr>
<td>Sludge Reduction</td>
<td>6%</td>
<td>3%</td>
</tr>
<tr>
<td>Oxygen (“Energy”) Reduction</td>
<td>Up to 10%</td>
<td>Up to 13%</td>
</tr>
</tbody>
</table>

Reduction figures are calculated on plant-wide basis

1. Introduction
The Ammonia Recovery Process (ARP) is a patented technology of the ThermoEnergy Corporation, and has been extensively studied at both the computational and pilot test level as a stand alone technology for the removal of ammonia from concentrated waste streams. Cost estimates for removal of about 90% of the centrate ammonia for the 85 mgd plant of NYC DEP (26th Ward) indicate that a capital cost of $15 million for centrate treatment would accomplish the same reduction as would a capital cost of $115 million for BNR applied to the main stream. Estimates of operating costs similarly indicated major reductions in costs for energy, chemicals, and sludge disposal.

Operating benefits for side-stream treatment of centrate can not be fully described in standard estimation worksheets due to the multiple interactions between processes involved in nutrient reduction in a WPCP. A leading water modeling firm, HydroQual, Inc, was hired by ThermoEnergy to conduct studies on the impact of centrate side-stream treatment with ARP on inputs needed for BNR. Outputs of the HydroQual study are the projected required process inputs to achieve a desired level of ammonia removal by the WPCP.

2. Background & Conditions Modeled

Contemporary WPCP are multi-stage bio-chemical facilities, with complex interaction of the stages. Simple linear reasoning is inadequate to describe the ecology of the active organisms, which controls operation at aerobic secondary treatment, anoxic and aerated zones of nutrient reduction, and the anaerobic digesters. Consideration of the feedback of intermediate streams and the behavior of clarifiers and dewatering devices reinforces the conclusion that a simulation that accounts for these phenomena is needed for a realistic computational model. The most widely used simulation software, and the one used for most NYC DEP models, is BioWin, developed by EnviroSim Associates. HydroQual was contracted by ThermoEnergy to conduct BioWin simulations to estimate the impact of ARP use on the inputs required for reduction of the ammonia effluent from a typical WPCP. All simulations were for steady-state operation at 20°C.

Two broad categories of WPCP were studied: single-sludge plants, such as those of NYC DEP, in which modification of the secondary treatment is employed for nutrient reduction, and two-sludge plants, such as the Blue Plains plant of WASA, in which separate treatment trains are used for carbonaceous BOD removal and nutrient reduction. Generic 100 mgd models were used for each of these categories, and performance of an example of each category was used to adjust the model operation parameters to match typical centrate ammonia concentration. Parameters were specified in the generic BioWin model for each category using default values for rate constants, tank volumes, etc, and identical influent characteristics were used for the two categories of plant. Total nitrogen in plant effluent of 5 ppm was achieved for the single-sludge model and the 2 ppm for the two-sludge case. This is displayed for the single-sludge case in Exhibit 1, and for the two-sludge case in Exhibit 2.

ARP is itself a sequence of steps that are dependent on both the waste stream to be treated and the effluent specifications. A version of ARP to be modeled for centrate treatment in this study takes the effluent from the vacuum separation step as the return stream to the plant. This preserves the alkalinity of that stream to be used in the plant’s BNR, while returning a stream with 100 ppm of ammonia-nitrogen. The effect of this application of ARP treatment of the centrate on chemical and energy inputs was projected for each category of plant. The BioWin model for each category was modified to include ARP as shown in Exhibits 1 and 2. Centrate flow to the head of the plant was eliminated in the ARP models and the ARP treated centrate introduced as a flow to the head end of the BNR process. The chemical (methanol and
alkalinity) and oxygen inputs to the BNR process were adjusted in order to keep effluent nitrogen the same for ARP and non-ARP results. Oxygen demand was taken as a surrogate for energy use since the major energy benefit of ARP is the decrease in aeration required. A conservative estimate of caustic demand for ARP based on full conversion of centrate bicarbonate to carbonate was employed. Input and output for ARP in these models is displayed in Exhibit 3.

In order to properly interpret the model results it is important to know the sensitivity to the model parameters. In this study the model parameters varied were influent TKN (sum of ammonia-nitrogen and organic nitrogen), SRT (solids retention time in secondary process for single-sludge, and the values for both secondary and BNR processes for two-sludge), and TS (total solids input to the anaerobic digester). Each of these parameters influences the solids sent to the anaerobic digester and thereby the ammonia influent to the ARP. These results are discussed in the following sections.

### 3. Findings

Identical influent streams are assumed for the two plant categories studied. The impact of ARP on plant operations is measured by changes in the following set of variables for each category.

<table>
<thead>
<tr>
<th>Input to Model of Wastewater Plant</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total “N” Load</td>
<td>Total nitrogen input to BNR = influent-N + Centrate-N</td>
</tr>
<tr>
<td>Sludge Produced</td>
<td>Total sludge output from plant</td>
</tr>
<tr>
<td>Alkalinity</td>
<td>Total alkalinity required for nutrient reduction and maintaining an effluent pH of 7.3</td>
</tr>
<tr>
<td>Methanol</td>
<td>Methanol required for BNR</td>
</tr>
<tr>
<td>Oxygen</td>
<td>Oxygen input for carbonaceous BOD removal and nitrification</td>
</tr>
</tbody>
</table>

The N-load on the BNR process for either category of plant includes recycled centrate (and small amounts from other recycle streams) as well as influent nitrogen. Typically nitrogen in recycled centrate is about 20-40% of the total N load. Sludge produced by the plant is reduced by ARP treatment of the centrate, since nitrifier bacterial growth in the BNR is reduced due to the ammonia removed by ARP. Alkalinity demand is similarly reduced in the BNR process by the removal of ammonia by ARP, while half of the alkalinity added for ARP is available for use in the treated centrate that is recycled to the BNR process. Methanol demand is obviously reduced as well by the removal of ammonia by ARP, but in addition the soluble carbon made available by anaerobic digestion is not affected by ARP and is returned to the BNR as bio-available carbon replacing an equivalent amount of methanol. Last, the oxygen demand is lowered by the reduced ammonia nitrogen load caused by removal of ammonia by ARP.

The sensitivity of the effect of ARP on each of these input requirements is also presented for each category of WPCP.

#### 3.1. Single-Sludge Plant

The single-sludge plant, as shown in Exhibit 1, adapts secondary treatment to achieve nitrification and denitrification. This allows considerable capital cost savings in retrofit of existing equipment. The left-two columns, Base Case, of Exhibit 4 demonstrate the ability of ARP to substantially reduce the input requirements for this category of plant. The % reduction of sludge
produced is less than the reduction in N load, since BNR is not the only source of bio-solids. Methanol reduction exceeds the reduction of nitrogen load since treated centrate and influent provide a source of bio-available carbon. Reduction of the nitrogen load to the equivalent of this available carbon would eliminate the methanol demand.

The generic model produced a centrate-N load of about 10% of influent TKN, whereas NYC DEP plants typically have centrate-N loads of about 20%. A calibrated site-specific model would be required for accurate estimation of savings to be achieved at a specific plant. However, the substantial % reductions in, methanol and alkalinity inputs and aeration are expected to be similar at an actual plant. The sensitivity results indicate that this is a robust conclusion.

3.2. Two-Sludge Plant

The two-sludge plant dedicates a separate process to nutrient reduction, as shown in Exhibit 2. The generic model demonstrates that the two categories of plant have materially different benefits from the application of ARP. Influent carbon and BNR recycle in the single-sludge category lowers demand for addition of both alkali and methanol relative to the two-sludge category. While the reduction of methanol demand related to ARP is over 6000 kg/d for the two-sludge and about 5300 kg/d for the single-sludge model, the percent reduction calculated for the single-sludge model is much higher due to the lower overall demand for the single-sludge category. A similar result was obtained for the alkali demand.

4. Conclusion

The generic BioWin model results are indicative of substantial savings in both operating and energy costs when ARP is integrated into the nutrient reduction design for either a single sludge or a two-sludge wastewater treatment plant. A more accurate estimate of cost savings for a specific plant requires use of actual plant parameters in the BioWin model and calibration of the model to match plant operational data, as well as unit prices for the process inputs and outputs for the plant location. The beneficial outputs include:
# Exhibit 1. BioWin Model for Single Sludge Model

Flow: 100 MGD  
Centrate TN: 795 mg/L at 0.41 MGD

<table>
<thead>
<tr>
<th>Influent Quality</th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow MGD</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>TKN mg/L</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>COD mg/L</td>
<td>290</td>
<td></td>
</tr>
<tr>
<td>CBOD mg/L</td>
<td>142</td>
<td></td>
</tr>
<tr>
<td>TSS mg/L</td>
<td>138</td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td>7.0</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Effluent Quality With ARP</th>
</tr>
</thead>
<tbody>
<tr>
<td>NH$_3$-N mg/L</td>
</tr>
<tr>
<td>NO$_3$-N mg/L</td>
</tr>
<tr>
<td>TN mg/L</td>
</tr>
<tr>
<td>COD mg/L</td>
</tr>
<tr>
<td>CBOD mg/L</td>
</tr>
<tr>
<td>pH</td>
</tr>
</tbody>
</table>

ARP is a Registered Trademark and Covered Under US Patent 7,270,796
Exhibit 2. BioWin Model for Two Sludge System

Flow: 100 MGD
Centrate TN: 795 mg/L at 0.41 MGD

<table>
<thead>
<tr>
<th>Influent Quality</th>
<th>Flow MGD</th>
<th>TKN mg/L</th>
<th>COD mg/L</th>
<th>CBOD mg/L</th>
<th>TSS mg/L</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100</td>
<td>25</td>
<td>290</td>
<td>142</td>
<td>138</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Effluent Quality</th>
<th>With ARP</th>
</tr>
</thead>
<tbody>
<tr>
<td>NH$_3$-N mg/L</td>
<td>0.06</td>
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<tr>
<td>NO$_3$-N mg/L</td>
<td>0.47</td>
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<tr>
<td>TN mg/L</td>
<td>1.96</td>
</tr>
<tr>
<td>COD mg/L</td>
<td>22.7</td>
</tr>
<tr>
<td>CBOD mg/L</td>
<td>3.1</td>
</tr>
<tr>
<td>pH</td>
<td>7.3</td>
</tr>
</tbody>
</table>
Exhibit 3: Parameters for ARP in BioWin Simulation

I/O for ARP

for HydroQual model of ARP return to BNR

Assume quantities in mass units
output of 100 ppm NH3-N independent of centrate NH3-N
mass ratios of caustic and acid to NH3 reduction are constant
for each NH3 removed, one HCO3 is lost and one CO3 is gained

units of ammonia removed = (centrate [NH3-N] - 100 ppm)*centrate volume

Inputs

<table>
<thead>
<tr>
<th></th>
<th>conc. %</th>
<th>g/gNH3-Nremoved</th>
</tr>
</thead>
<tbody>
<tr>
<td>H2SO4</td>
<td>conc.</td>
<td>3.50</td>
</tr>
<tr>
<td>NaOH</td>
<td>50%</td>
<td>5.71</td>
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</tbody>
</table>

output  

<table>
<thead>
<tr>
<th></th>
<th>conc. %</th>
<th>g/gNH3-Nremoved</th>
</tr>
</thead>
<tbody>
<tr>
<td>(NH4)2SO4</td>
<td>40%</td>
<td>11.79</td>
</tr>
<tr>
<td>CaCO3 equiv.</td>
<td>[input]</td>
<td>3.57</td>
</tr>
<tr>
<td>COD</td>
<td></td>
<td>0</td>
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</tbody>
</table>
## Exhibit 4: Summary of Single Sludge Sensitivity Analysis

<table>
<thead>
<tr>
<th>Model Conditions</th>
<th>Base Case</th>
<th>TKN = 40</th>
<th>High SRT</th>
<th>Higher SRT</th>
<th>High Sludge TS</th>
<th>Low Sludge TS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Units</strong></td>
<td>w/o ARP</td>
<td>W/ ARP</td>
<td>w/o ARP</td>
<td>W/ ARP</td>
<td>w/o ARP</td>
<td>W/ ARP</td>
</tr>
<tr>
<td>Influent TKN</td>
<td>mg/L</td>
<td>25</td>
<td>40</td>
<td>25</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>SRT</td>
<td>days</td>
<td>6.53</td>
<td>6.4</td>
<td>6.6</td>
<td>6.5</td>
<td>8.3</td>
</tr>
<tr>
<td>GT WAS</td>
<td>%TS</td>
<td>2.8</td>
<td>2.6</td>
<td>2.7</td>
<td>2.5</td>
<td>2.6</td>
</tr>
<tr>
<td>GT Primary Sludge</td>
<td>%TS</td>
<td>5.6</td>
<td>5.6</td>
<td>5.6</td>
<td>5.6</td>
<td>5.6</td>
</tr>
<tr>
<td>Centrate TKN</td>
<td>mg/L</td>
<td>1017</td>
<td>918</td>
<td>1087</td>
<td>1232</td>
<td>594</td>
</tr>
<tr>
<td><strong>Effluent Quality</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NO3-N</td>
<td>mg/L</td>
<td>2.8</td>
<td>2.8</td>
<td>5</td>
<td>5</td>
<td>2.8</td>
</tr>
<tr>
<td>pH</td>
<td>mg/L</td>
<td>7.3</td>
<td>7.3</td>
<td>7.3</td>
<td>7.3</td>
<td>7.3</td>
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<td><strong>Model Results</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total N Load</td>
<td>kg/day</td>
<td>11046</td>
<td>9738</td>
<td>17028</td>
<td>15472</td>
<td>9712</td>
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<tr>
<td>Reduction %</td>
<td></td>
<td>12%</td>
<td>9%</td>
<td>8%</td>
<td>7%</td>
<td>11%</td>
</tr>
<tr>
<td>Sludge Produced</td>
<td>kg/day</td>
<td>28600</td>
<td>26800</td>
<td>30800</td>
<td>28900</td>
<td>29500</td>
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<tr>
<td>Reduction %</td>
<td></td>
<td>6%</td>
<td>6%</td>
<td>8%</td>
<td>6%</td>
<td>6%</td>
</tr>
<tr>
<td>Alkalinity</td>
<td>Meq/day</td>
<td>2.50</td>
<td>2.24</td>
<td>3.00</td>
<td>2.71</td>
<td>2.65</td>
</tr>
<tr>
<td>Reduction %</td>
<td></td>
<td>10%</td>
<td>10%</td>
<td>13%</td>
<td>14%</td>
<td>11%</td>
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<tr>
<td>Methanol (COD)</td>
<td>kg/day</td>
<td>14280</td>
<td>8925</td>
<td>35700</td>
<td>25585</td>
<td>17850</td>
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<tr>
<td>Reduction %</td>
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<td>38%</td>
<td>28%</td>
<td>48%</td>
<td>49%</td>
<td>53%</td>
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<tr>
<td>Oxygen</td>
<td>kg/day</td>
<td>61200</td>
<td>55080</td>
<td>85680</td>
<td>75480</td>
<td>63240</td>
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<tr>
<td>Reduction %</td>
<td></td>
<td>10%</td>
<td>12%</td>
<td>10%</td>
<td>9%</td>
<td>13%</td>
</tr>
</tbody>
</table>

### Model Conditions
- **Influent TKN**: mg/L
- **SRT**: days
- **GT WAS %TS**:
- **GT Primary Sludge %TS**:
- **Centrate TKN**: mg/L

### Effluent Quality
- **NO3-N**: mg/L
- **pH**: mg/L

### Model Results
- **Total N Load**: kg/day
- **Sludge Produced**: kg/day
- **Alkalinity**: Meq/day
- **Methanol (COD)**: kg/day
- **Oxygen**: kg/day
## Exhibit 5. Summary of Two-Sludge Sensitivity Analysis

<table>
<thead>
<tr>
<th>Model Conditions</th>
<th>Base Case</th>
<th>TKN = 40</th>
<th>Lower SRT</th>
<th>Higher SRT</th>
<th>High Sludge TS</th>
<th>Low Sludge TS</th>
</tr>
</thead>
<tbody>
<tr>
<td>w/o ARP</td>
<td>With ARP</td>
<td>w/o ARP</td>
<td>With ARP</td>
<td>w/o ARP</td>
<td>With ARP</td>
<td>w/o ARP</td>
</tr>
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<td><strong>Influent TKN</strong> mg/L</td>
<td>25</td>
<td>40</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>25</td>
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<tr>
<td><strong>CBOD Stage</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>SRT</strong> days</td>
<td>1.4</td>
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<td>1.4</td>
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<td>1.9</td>
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<tr>
<td><strong>BNR Stage SRT</strong> days</td>
<td>12</td>
<td>11</td>
<td>11</td>
<td>11</td>
<td>16.2</td>
<td>16.2</td>
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<tr>
<td><strong>GT WAS</strong> %TS</td>
<td>2.4</td>
<td>2.3</td>
<td>2.6</td>
<td>2.5</td>
<td>3.1</td>
<td>3</td>
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<tr>
<td><strong>GT Primary Sludge</strong> %TS</td>
<td>5.5</td>
<td>5.5</td>
<td>5.5</td>
<td>5.4</td>
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<tr>
<td><strong>Centrate TKN</strong> mg/L</td>
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<td>934</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>NO3-N</strong> mg/L</td>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
</tr>
<tr>
<td><strong>pH</strong> mg/L</td>
<td>7.3</td>
<td>7.3</td>
<td>7.3</td>
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<td><strong>Model Results</strong></td>
<td></td>
<td></td>
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<tr>
<td><strong>Total N Load</strong> kg/day</td>
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<td>9911</td>
<td>17871</td>
<td>15678</td>
<td>11780</td>
<td>10035</td>
</tr>
<tr>
<td><strong>Reduction</strong> %</td>
<td>14%</td>
<td>12%</td>
<td>15%</td>
<td>13%</td>
<td>15%</td>
<td>13%</td>
</tr>
<tr>
<td><strong>Sludge Produced</strong> kg/day</td>
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<td>32000</td>
<td>33906</td>
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<td>32600</td>
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<td>4%</td>
<td>3%</td>
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<td>3%</td>
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<tr>
<td><strong>Alkalinity</strong> Meq/day</td>
<td>3.00</td>
<td>2.61</td>
<td>3.75</td>
<td>3.35</td>
<td>3.00</td>
<td>2.77</td>
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<tr>
<td><strong>Reduction</strong> %</td>
<td>13%</td>
<td>11%</td>
<td>8%</td>
<td>13%</td>
<td>13%</td>
<td>13%</td>
</tr>
<tr>
<td><strong>Methanol (COD)</strong> kg/day</td>
<td>33915</td>
<td>27370</td>
<td>53550</td>
<td>47600</td>
<td>33915</td>
<td>25585</td>
</tr>
<tr>
<td><strong>Reduction</strong> %</td>
<td>19%</td>
<td>11%</td>
<td>25%</td>
<td>20%</td>
<td>19%</td>
<td>19%</td>
</tr>
<tr>
<td><strong>Oxygen</strong> kg/day</td>
<td>63240</td>
<td>55080</td>
<td>86360</td>
<td>77520</td>
<td>57120</td>
<td>49640</td>
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<tr>
<td><strong>Reduction</strong> %</td>
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<td>13%</td>
<td>11%</td>
<td>12%</td>
<td>12%</td>
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