As consumer demand for detergent performance grows, so do expectations for low environmental impact detergent options. At the same time, environmental regulations are becoming more stringent in many countries, making it necessary for formulators to produce detergents that reduce potential negative impacts on wastewater and waterways, and reduce greenhouse gas emissions. Sodium Tripolyphosphate (STPP) is a traditional multipurpose ingredient in powder detergents. Because it contains phosphate, STPP can cause eutrophication and algae bloom if wastewater from washing machines merges into water bodies without the right treatment. If alternative detergent ingredients can be found to reduce the amount of STPP, aquatic environments should benefit. However, in order to be accepted by consumers, these alternatives need to have similar or improved wash performance, and not impose increased costs on detergents. Enzymes are a viable solution to this puzzle. New enzyme solutions have already been developed that open the door to cost-neutral opportunities for formulators to replace or supplement traditional chemicals with small amounts of enzymes. Enzymes are used for deep cleaning, stain removal, whiteness, and fabric and colour care. They are efficient at both low and high wash temperatures. By using enzymes it is possible to reduce the amount of other detergent ingredients, and to reduce the wash temperature without compromising performance (1).

THE IMPORTANCE OF PHOSPHORUS REMOVAL FROM WASTEWATER

In some parts of the world, wastewater treatment includes chemical and/or biological treatment where phosphorus is removed from the wastewater, resulting in minimal eutrophication (2). However, in other areas, where wastewater treatment is poor, phosphorus is emitted directly into rivers and seas. In regions where wastewater treatment is poor and STPP containing detergents are dominant, STPP may account for up to 28 percent of the available phosphorus in surface water (3). On June 30, 2013 the European Commission is adopting a ban on phosphates in laundry detergents even though many EU countries with sufficient wastewater treatment have already banned it. For countries that remove phosphate from wastewater, the ban will reduce pressure on wastewater treatment plants (with less phosphorous in the wastewater, treatment plants can reduce chemical use and sludge) and protect the environment in cases of overflow due to heavy rain. As of 2005, for example, wastewater treatment was not sufficient in the Black Sea region, which entirely or partially covers 23 countries. Along the Russian coast of the Black Sea, which is typical for the region, only 14 percent of all wastewater undergoes full biological processing. In no city along the Turkish Black Sea coast is there any treatment of wastewater (4). In such regions where phosphorus is not removed from the wastewater from household wash processes, the 15 g STPP that is used for each wash will lead to an emission of 12 g of phosphate ions per wash, equivalent to an emission of 3.8 g phosphorus (5). However, as the following study shows, these numbers can be improved and eutrophication can be prevented if STPP is replaced with alternative technologies.

Life Cycle Assessment: What is the environmental impact of using alternative builder systems with multiple enzymes?

Using enzymes in detergents is not just about improved wash performance and stabilized costs. CO₂ reduction from cold washing and compaction has been demonstrated (6). In order to move the industry towards phosphate-free detergents, Novozymes has investigated the possibilities of using enzymes to reduce the environmental impact of detergent builder systems.

### Table 1. Ingredients used for production of three model detergents. All data in gram per wash.

<table>
<thead>
<tr>
<th></th>
<th>Conventional (STPP)</th>
<th>Carbonate</th>
<th>Zeolite compact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surfactants</td>
<td>6.9</td>
<td>6.9</td>
<td>6.9</td>
</tr>
<tr>
<td>Linear alkylbenzene sulfonate (LAS)</td>
<td>1.4</td>
<td>1.4</td>
<td>1.4</td>
</tr>
<tr>
<td>Soap</td>
<td>1.4</td>
<td>1.4</td>
<td>1.4</td>
</tr>
<tr>
<td>Non-ionic surfactant (5-EO)</td>
<td>1.4</td>
<td>1.4</td>
<td>1.4</td>
</tr>
<tr>
<td>Builder components</td>
<td>15</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Sodium tripolyphosphate (STPP)</td>
<td>8.2</td>
<td>19.2</td>
<td>4.1</td>
</tr>
<tr>
<td>Na-carbonate (Na₂CO₃)</td>
<td>4.1</td>
<td>8.2</td>
<td>8.2</td>
</tr>
<tr>
<td>Na-dilicate (Na₂O·2Na₃O)</td>
<td>0</td>
<td>0</td>
<td>15</td>
</tr>
<tr>
<td>Zeolite A</td>
<td>0.69</td>
<td>0.69</td>
<td>0.69</td>
</tr>
<tr>
<td>Polycarboxylate</td>
<td>0.14</td>
<td>0.14</td>
<td>0.14</td>
</tr>
<tr>
<td>Phosphonate (HEDPA)²</td>
<td>0.14</td>
<td>0.14</td>
<td>0.14</td>
</tr>
<tr>
<td>Filters</td>
<td>37</td>
<td>27</td>
<td>13</td>
</tr>
<tr>
<td>Na-sulfate (Na₂SO₄)</td>
<td>27</td>
<td>27</td>
<td>13</td>
</tr>
<tr>
<td>Other components</td>
<td>3.4</td>
<td>3.4</td>
<td>3.4</td>
</tr>
<tr>
<td>Peroxide</td>
<td>0.09</td>
<td>0.09</td>
<td>0.09</td>
</tr>
<tr>
<td>Foamer</td>
<td>0.09</td>
<td>0.09</td>
<td>0.09</td>
</tr>
<tr>
<td>Enzyme products</td>
<td>0.09</td>
<td>0.15</td>
<td>0.15</td>
</tr>
<tr>
<td>Esterase 12 T</td>
<td>0.09</td>
<td>0.15</td>
<td>0.15</td>
</tr>
<tr>
<td>Catalase plus 12 T</td>
<td>0.09</td>
<td>0.15</td>
<td>0.15</td>
</tr>
<tr>
<td>Multi enzyme solution</td>
<td>0.21</td>
<td>0.21</td>
<td>0.21</td>
</tr>
<tr>
<td>Total weight</td>
<td>70</td>
<td>70</td>
<td>56</td>
</tr>
</tbody>
</table>
STPP is a standard builder ingredient in many areas of the world, including Eastern Europe. This study investigates the environmental implications if consumers in such regions were to switch from a typical STPP containing powder detergent to formulations with alternative builder systems containing multiple enzymes. The study has been conducted following the ISO guidelines ISO14040 and 140044 where all significant processes from “cradle to grave” are included (7).

The scope and method
The study compares builder systems based on three different ingredient systems: STPP with protease and amylase enzymes, carbonate with a multi-enzyme solution, and zeolite with a multi-enzyme solution. Wash tests were conducted that provide sufficient reason to believe that consumers will perceive the detergents as similar in performance.

Detergent composition
In most Western European countries, the use of STPP in laundry detergents has been phased out to prevent phosphates from leading to eutrophication and algae bloom. In June, 2013, phosphates will be banned from laundry detergents across the EU. Zeolites are the primary replacement for STPP in granular detergents today (8).

The STPP detergent is modelled after a typical powder detergent sold in Europe, the Middle East and Africa. Typical characteristics for such detergents are:

1. The content:
   a. Low enzyme content: <0.2 percent
   b. Builder components are STPP-based: ~ 40 percent
   c. Surfactants: ~ 14 percent
   d. Bleach components: ~ 6 percent
   e. Filler components: ~ 40 percent

2. No content of modern or recently proposed detergent ingredients, like methylglycin diacetic (MGDA) or copolymers. The alternative zeolite and carbonate detergents are modelled by Novozymes researchers to represent hypothetical future formulations that could be produced today or in the near future with readily available chemicals and enzyme products. The composition of the standard detergent and the two reformulations is shown in Table 1. In Table 2, the changes in formulations are summarized.

Wash and whiteness results
Two versions of each builder system were created – one version with enzymes and one version without. All six were tested for stain removal performance and whiteness on 21 stains. The results are shown in Figures 1 and 2.

All three builder systems perform decisively better with enzymes than without enzymes on both stain removal and whiteness. The zeolite system with multiple enzymes outperforms the other two systems on both whiteness and stain removal, while the STPP system with protease and amylase enzymes lags behind the other two.

System boundaries

1) STPP: Dosage is 5 g detergent per litre wash water, of which enzyme content is limited to 0.07 g protease and 0.07 g amylase.
2) Carbonate: Dosage is 5 g detergent per litre wash water, of which enzyme content is 0.91 g and consists of protease, amylase, mannanase, cellulase and lipase.
3) Zeolite in compacted formulation: Dosage is 4 g detergent per litre wash water and enzyme content is 1.3 percent, of which enzyme content is 0.91 g of protease, amylase, mannanase, cellulase and lipase.

All three detergents were tested at 40°C which is considered standard wash temperature in Europe. Resource extraction includes extraction of basic chemicals and fossil oil as well as agricultural cultivation of crops used to produce sugar, glucose, palm oil and soybean. Production of auxiliary materials such as artificial fertilizer, pesticides and machinery is included.

Figure 3. Main system boundaries of the study. Red boxes and arrows refer to added (induced) processes and material streams; green boxes and arrows refer to saved (displaced) processes and material/energy streams. Processes in the system, which remain nearly unchanged, are marked with dotted black boxes. Blue arrows indicate material streams that are changed as a result of the enzyme addition and chemical saving.
The study method is based on life cycle assessment (LCA) principles, where all significant processes in the product chain are included, from raw material extraction through production and use to final disposal. The LCA is performed according to the method described by JRC (2010) and environmental modelling is facilitated in SimaPro 7.2.4 LCA software.

**Environmental assessment**

The considered environmental impact categories include:
- Global warming (g CO$_2$ equivalents)
- Acidification (mg SO$_2$ equivalents)
- Eutrophication (mg PO$_4^3-$ equivalents)

In addition to environmental indicators, consumption of resources is addressed by including the following indicators in the assessment:
- Energy consumption (kJ primary energy carriers, Low Heat Value (LHV))
- Agricultural land use (m$^2$-a)
- Freshwater consumption (litres)
- Use of phosphate ore (kg)

Energy use plays an important role in the considered system and fuel consumption has been aggregated and quantified in terms of kJ (LHV). Enzymes are, to a large extent, based on agricultural production and use of agricultural land has been included in the assessment. Toxicity from the entire life cycle is excluded because the available data basis is considered incomplete. According to Pant et al. (2004), the largest toxic impacts of detergents are linked to emissions from household wash process wastewater. Toxicity impacts from wastewater are assessed in a toxicity screening. STPP is based on phosphorus, which is a crucial resource with a limited supply, given present use of artificial fertilizer in the world’s food production. Therefore use of phosphate ore is included in the assessment. Freshwater consumption has also been included because enzyme production requires freshwater.

**LCA RESULTS**

Characterized results of the environmental assessment are shown in Table 3 as net changes. The results refer to the situation where the STPP builder system is replaced by the alternative systems based on carbonate or zeolite with multi-enzyme solutions. There are net reductions for most of the environmental indicators, but not all. In Figures 4 and 5 below the results are shown as added versus saved environmental impacts for both alternative detergent formulations. There are meaningful potential benefits for global warming, eutrophication, and freshwater and phosphorus use. For agricultural land use and wastewater quality, there are potential environmental disadvantages – although miniscule in comparison to the other benefits.

Results for builder system based on carbonate and multiple enzymes

![Figure 4](image1.png)

**Table 3.** Net changes in environmental impact when consumers switch from STPP-based detergent to carbonate- or zeolite-based detergents. All data are per one wash of 2.7 kg laundry.
Sensitivity analysis for the environmental assessment
The above shows the environmental benefits of the alternative builder systems when the wastewater from the wash process is released into the environment without removal of phosphorus. If the wastewater from the washing machine is treated chemically for phosphorus removal, the situation is very different: there will be no benefit in terms of reduced eutrophication. Instead some chemicals for treating the wastewater are saved, leading to slightly larger savings in terms of CO₂.

Wastewater quality
The LCA includes an environmental hazard assessment of the quality of the wastewater from the wash process. Here the critical dilution volumes (CDV) are calculated for the ingredients used for the detergent formulation. These CDV values indicate a slightly increased impact on wastewater from the alternative builder systems compared with the STPP system. Novozymes is conducting further tests to understand if this is true implication or a result of the methodology.

CONCLUSIONS
Although many countries in Western Europe and North America have already phased out the use of STPP, other countries still use it as a standard builder ingredient. This has potential negative impacts on the environment, such as algae bloom and phosphorus depletion. Fortunately alternatives to STPP exist that offer the performance consumers have come to expect, without increasing the production cost of the detergent. New detergents based on carbonate and zeolite with multi-enzyme solutions have been modelled and performance tested. The results confirm that replacing STPP builder systems is one good step towards reducing phosphorus in wastewater and water ways. Both carbonate- and zeolite-based builder systems provide potential meaningful benefits for global warming, eutrophication and freshwater and phosphorus use. These builder systems also provide improved wash performance making them acceptable to consumers. Uncertainty assessments, data-quality assessments and sensitivity analyses indicate that the general conclusion of the study is robust, although magnitudes of environmental advantages are subject to much variation and uncertainty. Solutions towards a phosphate-free future are available and viable. Novozymes is working further to understand potential negative environmental impacts such as wastewater quality (chronic and acute). At the same time, the industry should embrace alternative builder systems and begin to move forward with testing and implementing them. Novozymes is pleased to join forces with colleagues across the detergent industry value chain to realize their potential in the years to come.

REFERENCES AND NOTES
7. www.iso.org