LCA comparative analysis of different technologies for functional coating in food applications

Gabriela Benveniste
Environment Park S.p.A. – Turin, Italy

Innovation for Sustainable Production, April 23rd, 2008, Bruges, Belgium
SUMMARY

• PROJECT FRAME AND AIMS
• LCA METHODOLOGY
• BOUNDARIES, F.U & INVENTORY
• RESULTS
• FINAL COMMENTS
SUMMARY

• PROJECT FRAME AND AIMS
• LCA METHODOLOGY
• BOUNDARIES, F.U & INVENTORY
• RESULTS
• FINAL COMMENTS
Environment Park S.p.A.

Environmental Scientific and Technological Park

Born by initiative of Regione Piemonte, Provincia di Torino, Comune di Torino, in a wide industrial dismissed area

Environment Park has been realized in the context of European Union Structural Funds and nowadays is an Joint Stock company receiving most of the capital from public organizations as: Comune di Torino, Finpiemonte S.P.A., SMAT, AMIAT, IRIDE ENERGIA, CCIAA di Torino, Unione Industriale, Provincia di Torino, Università di Torino

Environment Park site contains Research and Development organizations as well as companies working on eco–efficient and innovative technologies.
Clean NT Lab PVD deposition facilities

Plasma Vapour Deposition (PVD) Arc-DC facility for the development of innovative ceramics coatings to be deposited on conductive thermo-resistant metals and alloys – (process temperature >160°C)
SCHEMATICS OF PVD DEPOSITION SETUP
PROJECT AIMS

Investigate the available and future technologies for surface functionalisation to obtain anti corrosion properties, on a comparative basis with specific reference to their environmental life-cycle burden.

- Compare alternative technologies for surface functionalisation – process analysis
- Estimate the overall environmental burden for each technology through LCA Analysis
SUMMARY

• PROJECT FRAME AND AIMS
• LCA METHODOLOGY
• BOUNDARIES, F.U & INVENTORY
• RESULTS
• FINAL COMMENTS
What is LCA? From cradle to...

LCA is a technique for assessing the environmental aspects and potential impacts associated with a product/process, by compiling an inventory of relevant inputs and outputs of a product system, evaluating the potential environmental impacts associated with those inputs and outputs, interpreting the results in relations to the objectives of the study.

Innovation for Sustainable Production, April 23rd, 2008, Bruges, Belgium
LCA STEPS : ISO 14040- 44

LCA framework
- Goal and Scope Definition
- Inventory Analysis
- Impact Assessment

Interpretation

Direct applications
- Product development and improvement
- Strategic planning
- Public policy making
- Marketing
LCA Methodology

Process (Traditional or innovative)

Final product: functionalised surface

Outputs (air emissions, water emissions, solids, ...)

Inputs (energy, raw materials)

BOUSTEAD MODEL V

Total emissions

Total raw materials

GER  GWP  Acid  POPC  EU

Innovation for Sustainable Production, April 23rd, 2008, Bruges, Belgium
LCA Methodology - glossary

- **Global Warming Potential in 100 years (GWP100):** index used to measure the global warming, that is the phenomenon, whereby CO2 in the atmosphere, along with others compounds, absorbs infra-red radiation emitted from the Earth’s surface giving rise to an increase in temperature. In others words, GWP is the measure, based on concentration and on exposition time, of the potential contribute that a substance causes to greenhouse effect as to that caused by the same weight of CO2. The standardisation of global warming is made reporting the amounts of the inventoried substances to g of CO2-equivalents.

- **Acidification Potential (AP):** index used to measure the acidification impact into the atmosphere and water courses caused by the release of hydrogen ions. The standardisation of acidification is made reporting the amounts of the inventoried substances to g of H+equivalents.

- **Eutrophication Potential (EP):** index used to measure the nutrient enrichment (eutrophication), which in turn may result in algal blooms, caused by the release of sulphur nitrogen, phosphorous and degradable organic substances into the atmosphere and water courses. The standardisation of eutrophication is made reporting the amounts of the inventoried substances to g of O2equivalents.

- **Ozone Depletion Potential (ODP):** index used to measure the breakdown of the stratospheric ozone layer, which should protect from ultraviolet radiation, caused by the emissions of reactive substances mainly originated from Chlorofluorocarbons (CFC). The standardization of Ozone depletion is made reporting the amounts of the inventoried substances to g of CFC-11-equivalents.

- **Energy mix:** the balance between various sources of energy in primary energy consumption (i.e. France vs Italy)

- **GER:** is the Gross Energy Requirement, that is to say, the total amount of energy required by the process/product in study referred to direct energy, indirect energy, transport energy, feedstock energy.
PROJECT SCENARIOS

The main objective of this work is to calculate the energy and environmental burdens generated by ceramics PVD-, SiOx Plasma- and Chromium electroplating-coating processes using different energy mixes.

In detail, data, calculation procedure and results refer to:

- PVD Arc DC ion-plating equipment;
- SiOx deposition from plasma experimental process carried
- Chromium electroplating process performed by typical electroplating process
LCA ANALYSIS - HYPOTHESIS

For the GER (Gross Energy Requirement) results it has been taken into account the values of the energy consumption referred to the European Energy Mix. When stated, it has also been considered the Italy Energy Mix and France Energy Mix.

<table>
<thead>
<tr>
<th>Source</th>
<th>Italy Mix</th>
<th>Europe Mix</th>
<th>France Mix</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>12%</td>
<td>27%</td>
<td>7%</td>
</tr>
<tr>
<td>Fuel</td>
<td>34%</td>
<td>8%</td>
<td>2%</td>
</tr>
<tr>
<td>Gas</td>
<td>34%</td>
<td>16%</td>
<td>1%</td>
</tr>
<tr>
<td>Hydroelectrics</td>
<td>10%</td>
<td>6%</td>
<td>7%</td>
</tr>
<tr>
<td>Nuclear</td>
<td>9%</td>
<td>39%</td>
<td>82%</td>
</tr>
<tr>
<td>Other sources</td>
<td>1%</td>
<td>2%</td>
<td>1%</td>
</tr>
</tbody>
</table>
LCA ANALYSIS - HYPOTHESIS

- Indirect energy for Natural Gas consumption have been considered using Italy scenario
- All the values are referred to the established Functional Unit (F.U.)
- The analysis does not take into account the production of the substrates, tools and machinery for the process, nor industrial systems
- The results regard the environmental point of view. No budget considerations at that point.

More specific hypothesis are described for each case study.
SUMMARY

• PROJECT FRAME AND AIMS
• LCA METHODOLOGY
• BOUNDARIES, F.U & INVENTORY
• RESULTS
• FINAL COMMENTS
System Boundaries

Untreated surface

Chemical compounds

Direct energy

PVD or Electroplating or SiOx

Emissions

Treated surface

Innovation for Sustainable Production, April 23rd, 2008, Bruges, Belgium
Anti corrosion coatings for food industry applications (traditional and SiOx deposition)

Comparing:
- Traditional Cr plating
- SiOx Plasma deposition
- TiN/TiCN PVD plasma deposition

Extra hypothesis:
- Comparing 3 different energy mix (Italy, France, Europe)
  - F.U. = 1 m² x 1µm or 1m² x 3µm
Case study - anti-corrosion coatings for food industry applications - PVD deposition

Mass and Energy Balance of PVD Process

- TiN PVD Coating
  - Electricity: 121 MJ
  - Ar: 0.9 g
  - N₂: 52.2 g
  - Ti: 7.8 g
  - Detergent: 15 g
  - Lubricating oil: 12.5 g
  - N₂: 50 g
  - Ar: 0.9 g
  - Isopropanol: 12.3 g
  - 1 m², 1 μm surface treated

Air Emission

- TiCN PVD Coating
  - Electricity: 121 MJ
  - Ar: 1.8 g
  - C₂H₂: 4.4 g
  - N₂: 45.6 g
  - Ti: 12.4 g
  - Detergent: 15 g
  - Lubricating oil: 12.5 g
  - N₂: 42 g
  - Ar: 1.8 g
  - C₂H₂: 0.7 g
  - H₂: 0.3 g
  - Isopropanol: 12.2 g
  - 1 m², 1 μm surface treated
PVD process scheme

VACUUM CHAMBER

- Ionised metal vapour or alloys (plasma state)
- Electric ionization of the vapour
- Crystallisation of the metallic plasma or compounds
- Condensation of the plasma components on the substrate
- Formation of a chemical compound on the surface of the substrate

PVD coated product

Raw materials

Energy

Tranports (procurement and materials handling)

Emissions

Innovation for Sustainable Production, April 23rd, 2008, Bruges, Belgium
SUMMARY

- PROJECT FRAME AND AIMS
- LCA METHODOLOGY
- BOUNDARIES, F.U & INVENTORY
- RESULTS
- FINAL COMMENTS
## RESULTS

### Energy consumption

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Production energy</th>
<th>Energy Use</th>
<th>Transport energy</th>
<th>Feedstock energy</th>
<th>Total energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>PVD- TiCN Italy Mix</td>
<td>255</td>
<td>124</td>
<td>2</td>
<td>0</td>
<td>381</td>
</tr>
<tr>
<td>PVD- TiCN Europe Mix</td>
<td>248</td>
<td>124</td>
<td>2</td>
<td>1</td>
<td>375</td>
</tr>
<tr>
<td>PVD- TiCN France Mix</td>
<td>255</td>
<td>124</td>
<td>2</td>
<td>1</td>
<td>381</td>
</tr>
<tr>
<td>PVD- TiN Italy Mix</td>
<td>255</td>
<td>124</td>
<td>2</td>
<td>0</td>
<td>381</td>
</tr>
<tr>
<td>PVD- TiN Europe Mix</td>
<td>248</td>
<td>124</td>
<td>2</td>
<td>1</td>
<td>375</td>
</tr>
<tr>
<td>PVD- TiN France Mix</td>
<td>255</td>
<td>124</td>
<td>2</td>
<td>1</td>
<td>381</td>
</tr>
<tr>
<td>CrVI Galvanic Italy mix</td>
<td>187.3</td>
<td>115</td>
<td>2,5</td>
<td>0,9</td>
<td>306</td>
</tr>
<tr>
<td>CrVI Galvanic Europe mix</td>
<td>187.3</td>
<td>115</td>
<td>2,5</td>
<td>0,9</td>
<td>306</td>
</tr>
<tr>
<td>CrVI Galvanic France mix</td>
<td>182.3</td>
<td>115</td>
<td>2,5</td>
<td>0,9</td>
<td>300</td>
</tr>
<tr>
<td>SiOx plasma Italy mix</td>
<td>607</td>
<td>348</td>
<td>6</td>
<td>41</td>
<td>1002</td>
</tr>
<tr>
<td>SiOx plasma Europe mix</td>
<td>587</td>
<td>348</td>
<td>6</td>
<td>41</td>
<td>982</td>
</tr>
<tr>
<td>SiOx plasma France mix</td>
<td>607</td>
<td>348</td>
<td>6</td>
<td>41</td>
<td>1002</td>
</tr>
</tbody>
</table>
Energy major consumption - contributors

Considering the contribution on the GER of the raw materials used in each process firstly it should be said that this is not significantly related to the energy mix. Respectively, the contributions of the raw material represent:

- 17% of the GER in SiOx deposition process (hexamethyldisiloxane production)
- 1.5-2% of the GER in PVD process (titanium production)
- 4% of GER in Chromium electroplating process (production of CrO3)
# RESULTS

## Anti - corrosion treatments

### Environmental Parameters

<table>
<thead>
<tr>
<th>TREATMENT</th>
<th>GWP (kg CO2)</th>
<th>AP (g eq SO2)</th>
<th>POPC (g C2H4)</th>
<th>EU (g PO43)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PVD - TiCN Italy Mix</td>
<td>23.53</td>
<td>276.79</td>
<td>32.75</td>
<td>8.76</td>
</tr>
<tr>
<td>PVD - TiCN Europe Mix</td>
<td>17.36</td>
<td>140.63</td>
<td>15.32</td>
<td>5.98</td>
</tr>
<tr>
<td>PVD - TiCN France Mix</td>
<td>4.19</td>
<td>38.88</td>
<td>7.45</td>
<td>1.71</td>
</tr>
<tr>
<td>PVD- TiN Italy Mix</td>
<td>23.39</td>
<td>245.47</td>
<td>32.38</td>
<td>8.71</td>
</tr>
<tr>
<td>PVD- TiN Europe Mix</td>
<td>17.22</td>
<td>139.32</td>
<td>14.95</td>
<td>5.93</td>
</tr>
<tr>
<td>PVD- TiN France Mix</td>
<td>4.05</td>
<td>37.6</td>
<td>7.08</td>
<td>1.66</td>
</tr>
<tr>
<td>CrVI Galvanic Italy mix</td>
<td>18.93</td>
<td>210.52</td>
<td>22.44</td>
<td>6.92</td>
</tr>
<tr>
<td>CrVI Galvanic Europe mix</td>
<td>14.38</td>
<td>110.13</td>
<td>9.59</td>
<td>4.86</td>
</tr>
<tr>
<td>CrVI Galvanic France mix</td>
<td>4.76</td>
<td>35.68</td>
<td>3.60</td>
<td>1.73</td>
</tr>
<tr>
<td>SiOx plasma Italy mix</td>
<td>59.78</td>
<td>718.75</td>
<td>75.99</td>
<td>22.92</td>
</tr>
<tr>
<td>SiOx plasma Europe mix</td>
<td>46.21</td>
<td>419.44</td>
<td>37.66</td>
<td>16.8</td>
</tr>
<tr>
<td>SiOx plasma France mix</td>
<td>17.38</td>
<td>197.35</td>
<td>20.54</td>
<td>7.46</td>
</tr>
</tbody>
</table>
Energy mix contribution to GWP

The energy mix clearly affects the GWP parameter.
Raw materials consumption and water emissions

Innovation for Sustainable Production, April 23rd, 2008, Bruges, Belgium
SUMMARY

• PROJECT FRAME AND AIMS
• LCA METHODOLOGY
• BOUNDARIES, F.U & INVENTORY
• RESULTS
• FINAL COMMENTS
**FINAL COMMENTS**

Chromium plating process determines a huge local or localised environmental burden while PVD and plasma deposition of SiOx determine a greater environmental burden on global scale.

- The energy mix does not affect significantly the energy consumption for the same process.
- Cr coatings requires less process (direct) energy (115 MJ/f.u.) respect to the PVD/plasma processes (124 MJ/f.u.) and 348 MJ/f.u. This is especially relevant for the electricity consumption: the Cr process requires only 89.2 MJ el/f.u. while the PVD process 122 MJ el/f.u and SiOx 288 MJ/f.u.

- The energy mix to produce electricity is therefore relevant to define the environmental burden of the two systems.

- In the case of PVD, the use of renewable electricity sources and the increment of the process efficiency could be a good way to improve the environmental performances.
FINAL COMMENTS

- From a local environmental point of view, the PVD process avoids the direct emissions of metals (Cr, Zn and Cu in particular) but it generates an indirect contribution from the electrical power plant.

- Furthermore, it should be remarked that input data used for Chromium electroplating are very conservative, as it has not been considered that for a productive process of technical galvanisation the concentration of CrO3 in the electrolytic bath is in average a 30% higher than for the process considered here.

- PVD coating technology eliminates the need, risk and relevant cost of post processing since there is no emission in water and main direct emission source to air is Nitrogen. So no additional technical complexity or extra cost for by products post-treatments are required.
Thank you for your attention!

Contact: Gabriela Benveniste

@  gabriela.benveniste@envipark.com