A joint initiative of the ETH domain and Swiss Federal Offices
metals treatment and compressed air supply

Rolf Frischknecht, Roland Steiner
ESU-services Ltd.
Contents

• Overview of processes analysed
• General modelling principles
• Description of life cycle inventories of machine processing
• Conclusions
Overview of processes analysed

- Average machine processing
- Degreasing of metal surfaces
- Chipping
- Laser machining
- Chippless shaping
- compressed air supply
Modelling principles: capital equipment

- factory infrastructure:
  demand of a share of capital equipment included in all machining datasets

- exception “laser machining”:
  no factory hall demand included, as no correlation between machining hours and factory infrastructure

- exception “compressed air supply”:
  considered ancillary process (e.g., to metals machining) in a factory
Modelling principles: Degreasing

- machining datasets do NOT include degreasing
  Reason:
  - machining is per mass (or time in the case of laser machining)
  - degreasing is per surface
- “surface to mass” ratio must be known
- practitioner needs to add degreasing dataset to each individual machining dataset
Modelling principles: Reference unit and material input

• chipping datasets:
  - per kg material removed
  - material removed is an input

• chipless shaping:
  - per kg material processed
  - no material input

• laser machining:
  - per hour processing
  - no material input (a few mg/sec)

• compressed air supply:
  - per m³ comp. air supplied (including losses in the network)
  - per m³ comp. air produced
Average machine processing

- average product manufacturing:
  steel
  chromium steel
  aluminium
  copper
  metal (82.4/2.0/3.3/12.2 %)

- additional datasets:
  - machine (manufacturing)
  - machine operation
  - factory (construction)
  - factory operation
  - metal input
Inventory data

- Data from 8 mechanical processing machines
- Average capacity about 8’000 tons from 44 to 210’000 tons capacity
- data from 2003 to 2006
- data includes
  - solvents, consumption
  - solvents, emission: 0.56g/kg metal product
  - lubricating oil
  - compressed air
  - thermal energy
  - electricity
machine and factory

- manufacture data: based on the same 8 machines
- factory operation: ancillary energy consumption, water consumption and wastes generated
- metal working factory:
  - includes building hall and land use
  - data based on three manufacturers
Degreasing of metals

- industry data from European household device manufacturer
- inventory data includes:
  - electricity
  - thermal energy
  - industrial cleaning detergents
  - sodium chloride
  - sulphuric acid
  - water
Turning

- Two phases in treatment: roughing, dressing and average
- Two different technologies: conventional and CNC (Computerized Numerical Control)
- Five different metals: steel, NiCr-steel, cast iron, aluminium, brass
- Inventory data:
  - electricity
  - compressed air (CNC only)
  - lubricating oil (CNC only)
  - factory (operation and construction)
  - amount of metal removed
Results: ecological scarcity 06

<table>
<thead>
<tr>
<th>Material</th>
<th>Ecopoints/kg removed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminium</td>
<td></td>
</tr>
<tr>
<td>Brass</td>
<td></td>
</tr>
<tr>
<td>Cast iron</td>
<td></td>
</tr>
<tr>
<td>Chromium</td>
<td></td>
</tr>
<tr>
<td>Steel</td>
<td></td>
</tr>
</tbody>
</table>

- **Aluminium**: Minor contribution in ecological scarcity.
- **Brass**: Significant contribution, primarily in land use and natural resources.
- **Cast Iron**: Moderate contribution, primarily in energy resources.
- **Chromium**: Minor contribution, primarily in emission into ground water.
- **Steel**: Moderate contribution, primarily in land use and energy resources.
Contributions: ecological scarcity 06

- Emission into top soil
- Waste
- Land use
- Natural resources
- Energy resources
- Emission into ground water
- Emission into surface water
- Emission into air

Graph showing contributions to ecological scarcity from various activities:
- Electricity
- Machine
- Factory
- Factory operation
- Aluminium

The graph indicates the ecopoints/kg removed for each activity, with aluminium having the highest contribution.
Drilling

- Two different technologies: conventional and CNC
- Five different metals: steel, chromium steel, aluminium, copper, brass
- Inventory data:
  - electricity
  - compressed air (CNC only)
  - lubricating oil (CNC only)
  - capital equipment
  - factory operation
  - amount of metal removed
Results: ecological scarcity 06

![Graph showing ecological scarcity for different materials and processes](image)

- **Aluminium**, **Brass**, **Cast Iron**, **Chromium**, **Steel**
- **CNC drilling**
- **Ecopoints/kg removed**

Legend:
- Emission into top soil
- Waste
- Land use
- Natural resources
- Energy resources
- Emission into ground water
- Emission into surface water
- Emission into air
Milling

- Four different process modes:
  large and small parts, dressing and average
- Four different metals:
  steel, chromium steel, cast iron, aluminium
- Inventory data:
  - electricity
  - compressed air
  - lubricating oil
  - amount of metal removed
Results: ecological scarcity 06

![Bar chart showing ecological scarcity for different materials.

- Aluminium:
  - Emission into top soil: 2000
  - Waste: 4000
  - Land use: 6000
  - Natural resources: 8000
  - Energy resources: 10000
  - Emission into ground water: 12000
  - Emission into surface water: 14000
  - Emission into air: 16000

- Cast iron:
  - Emission into top soil: 2000
  - Waste: 4000
  - Land use: 6000
  - Natural resources: 8000
  - Energy resources: 10000
  - Emission into ground water: 12000
  - Emission into surface water: 14000
  - Emission into air: 16000

- Chromium steel:
  - Emission into top soil: 2000
  - Waste: 4000
  - Land use: 6000
  - Natural resources: 8000
  - Energy resources: 10000
  - Emission into ground water: 12000
  - Emission into surface water: 14000
  - Emission into air: 16000

- Steel:
  - Emission into top soil: 2000
  - Waste: 4000
  - Land use: 6000
  - Natural resources: 8000
  - Energy resources: 10000
  - Emission into ground water: 12000
  - Emission into surface water: 14000
  - Emission into air: 16000

Presentation: Rolf Frischknecht
Contributions: ecological scarcity 06

- Emission into top soil
- Waste
- Land use
- Natural resources
- Energy resources
- Emission into ground water
- Emission into surface water
- Emission into air

Diagram showing contributions to ecological scarcity in milling, average.

Presentation: Rolf Frischknecht
Laser machining of metals

- Two different laser systems:
  - YAG (Yttrium-Aluminium garnet)
  - CO$_2$

- Different laser sizes:
  - YAG: 30, 40, 50, 60, 120, 200, 330, 500 W
  - CO$_2$: 2, 2.7, 3.2, 4.0, 5.0, 6.0 kW

- Total operation time:
  - YAG: 2 hours/day; 5 days/week; 15 years
  - CO$_2$: 12 hours/day; 5 days/week; 15 years
Laser machining: inventory data

- YAG laser systems:
  - electricity
  - cooling water (larger units only)
  - air emissions of particulates, \( \text{NO}_x \), and ozone
  - machine manufacture

- \( \text{CO}_2 \) laser systems:
  - electricity
  - industrial gases (helium, nitrogen, carbon dioxide)
  - air emissions of helium, particulates, \( \text{NO}_x \), \( \text{CO}_2 \), and ozone
  - machine manufacture
Results: ecological scarcity 06

- YAG, 40W
- YAG, 120W
- YAG, 500W
- CO2, 2000W
- CO2, 6000W

- Emission into top soil
- Waste
- Land use
- Natural resources
- Energy resources
- Emission into ground water
- Emission into surface water
- Emission into air
Contributions: ecological scarcity 06

- Laser machining of metal, YAG, 500W
- Contributions include:
  - Laser machining
  - Electricity
  - Industrial gases
  - Machine
  - Transports

- Emission contributions:
  - Emission into top soil
  - Waste
  - Land use
  - Natural resources
  - Energy resources
  - Emission into ground water
  - Emission into surface water
  - Emission into air

- Ecopoints/hour operation:
  - Laser machining: 0
  - Electricity: 45,000
  - Industrial gases: 10,000
  - Machine: 500
  - Transports: 0

- Overall ecological scarcity: 0
Impact extrusion

- Three different levels of temperature:  
  cold ($T/T_{\text{melt}} < 0.3$), warm, hot ($T/T_{\text{melt}} > 0.6$)
- two different metals:  
  - steel  
  - aluminium (cold IE only)
- Datasets on  
  - surface treatment (cold IE only)  
  - warming (warm/hot IE only)  
  - deformation stroke  
  - 1 to five stroke treatments
- Inventory data:  
  energy inputs, capital equipment and factory operation
Results: ecological scarcity 06

- Cold, aluminium
- Cold, steel
- Warm, steel
- Hot, steel

Impact extrusion, 5 strokes

<table>
<thead>
<tr>
<th>Material</th>
<th>Emission into Top Soil</th>
<th>Waste</th>
<th>Land Use</th>
<th>Natural Resources</th>
<th>Energy Resources</th>
<th>Emission into Ground Water</th>
<th>Emission into Surface Water</th>
<th>Emission into Air</th>
</tr>
</thead>
</table>
Contributions: ecological scarcity 06

Impact extrusion, aluminium, 5 strokes

- Emission into top soil
- Waste
- Land use
- Natural resources
- Energy resources
- Emission into ground water
- Emission into surface water
- Emission into air

Ecopoints/kg processed

- Deformation stroke
- Surface treatment
- Heat treatment
- Compressed air
- Machine
- Factory
- Factory operation
Deep drawing

- Two different modes: single stroke and continuous
- Different press sizes: 650, 3’500, 10’000, 38’000 kN
- one metal: steel
- Inventory data:
  - electricity,
  - compressed air
  - capital equipment
  - factory operation
Compressed air supply
Compressed air supply system

- compressor
- compressed air storage container (opt.)
- dryer (opt.)
- filter (opt.)
- pipe network (for distribution)
- consumer devices
Drivers of electricity consumption

- leakage rate
- pressure level
- appropriateness of control settings
- size of compressor

increase in electricity consumption due to filter and dryer:
- small installations: 5 %
- large installations: 3 %
### Compressors installed in Switzerland

<table>
<thead>
<tr>
<th>installed compressors</th>
<th>power in kW</th>
<th>total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;3</td>
<td>3-15</td>
</tr>
<tr>
<td>installed</td>
<td>110‘000</td>
<td>30‘000</td>
</tr>
<tr>
<td>compressors</td>
<td>74 %</td>
<td>20 %</td>
</tr>
<tr>
<td>electricity consumption</td>
<td>11</td>
<td>150</td>
</tr>
<tr>
<td>[GWh]</td>
<td>1 %</td>
<td>20 %</td>
</tr>
</tbody>
</table>

Presentation: Rolf Frischknecht
Key figures compressors & network

- life time: 15 years
- 750 hours per year
- machine weight:
  4 kW: 140 kg (35 kg/kW)
  300 kW: 4600 kg (15 kg/kW)
- increase in electricity consumption due to filter and dryer:
  - small installations: 5 %
  - large installations: 3 %
- pipe diameter: 100 mm
- network length: 4’500 m
- 100 mg steel (large), 34 mg aluminium (small) per Nm³
Datasets available

- Two different compressor sizes: 
  <30 kW, >30 kW
- Three different pressure levels: 
  - <30 kW: 8, 10, 12 bar
  - >30 kW: 6, 7, 8 bar
- Three different technology levels: 
  - average
  - optimised
  - best generation (>30 kW only)
Electricity consumption

- Average, large
- Optimised, large
- Best generation, large
- Average, small
- Optimised, small

Graph showing the electricity consumption in kWh/Nm³ at compressor average, large, optimised, large, best generation, large, average, small, optimised, small.
Inventory data

- leakage rate > 30 kW:
  - average: 30 %
  - optimised: 15 %
  - best generation: 10 %

- leakage rate < 30 kW:
  - average: 50 %
  - optimised: 5 %

- lubricating oil:
  - small: 10 mg / Nm$^3$
  - large: 2.1 mg / Nm$^3$
Results: cumulative energy demand

<table>
<thead>
<tr>
<th>Type</th>
<th>Energy Demand (MJ-eq/Nm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small, 10 bar,</td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td></td>
</tr>
<tr>
<td>Optimised</td>
<td></td>
</tr>
<tr>
<td>Large, 7 bar,</td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td></td>
</tr>
<tr>
<td>Optimised</td>
<td></td>
</tr>
<tr>
<td>Optimised, best</td>
<td></td>
</tr>
</tbody>
</table>

- Wind
- Water
- Solar
- Primary forest
- Nuclear
- Geothermal
- Fossil
- Biomass

Compressed air, supplied
Results: ecological scarcity 06

- <30kW, 8 bar
- <30kW, 10 bar
- <30kW, 12 bar
- >30kW, 6 bar
- >30kW, 7 bar
- >30kW, 8 bar

Legend:
- Green: Waste
- Yellow: Land use
- Orange: Energy resources
- Blue: Natural resources
- Brown: Emission into top soil
- Light blue: Emission into surface water
- Pink: Emission into air

Graph shows the ecological scarcity results for different compressed air supplies, optimised.
Contributions: ecological scarcity 06

- Compressor, 4 kW: 300 ecpooints/Nm³ produced
- Lubricating oil: 250 ecpooints/Nm³ produced
- Electricity: 100 ecpooints/Nm³ produced
- Transport: 50 ecpooints/Nm³ produced
- Disposal: 300 ecpooints/Nm³ produced

Emissions:
- Emission into ground water
- Waste
- Land use
- Natural resources
- Energy resources
- Emission into top soil
- Emission into surface water
- Emission into air

Compressed air supply, small, 10 bar
Contributions: ecological scarcity 06

- compressor, 300 kW
- lubricating oil
- electricity
- transport
- disposal

Graph showing contributions to ecological scarcity with categories:
- emission into ground water
- waste
- land use
- natural resources
- energy resources
- emission into top soil
- emission into surface water
- emission into air

The image shows a large industrial machine.
Conclusions

- chipping processes: production of material removed is dominant
- chipless shaping: deformation energy and general factory operation are most important
- laser machining dependent on power needed
- compressed air: substantial difference particularly between average, optimised and best
- metal machining datasets do not include degreasing => add it separately
Thank you very much for your attention!

Rolf Frischknecht
frischknecht@esu-services.ch