



# Principles of Design for Sustainability for Structures

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# “Triple Bottom Line” of Sustainability

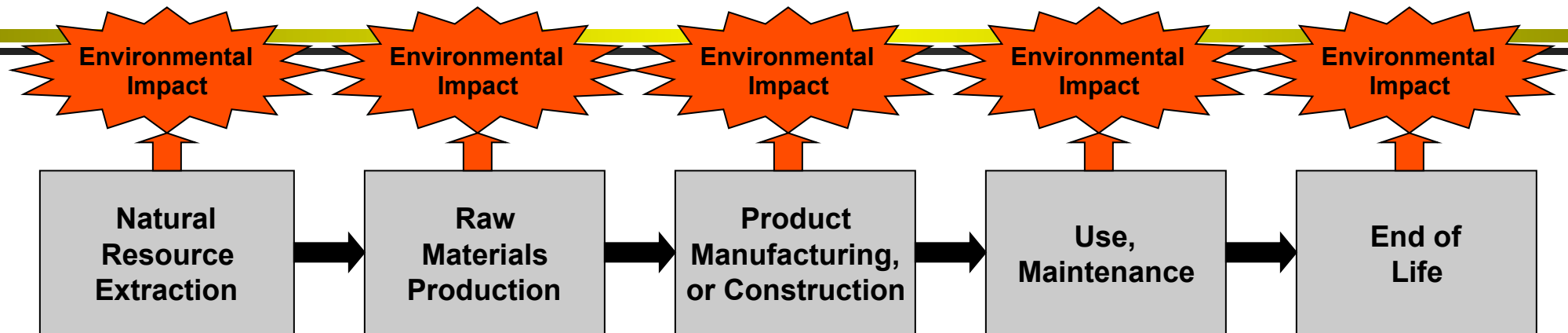
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- *The original definition of “sustainable development:”*  
"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs." (Bruntland Commission 1987)
- Environmental: natural systems, public health
- Economic: life-cycle costs, investments, job creation, taxes, public and private services
- Social: safety, equity, civil rights, justice, security, ...

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# **The Principles are Critical: Life-Cycle Thinking and the Precautionary Principle**

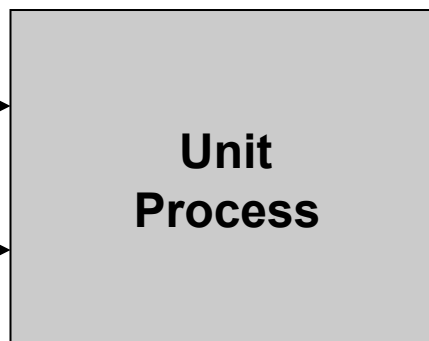
# Life-cycle Assessment (LCA)



## Inputs

Materials

Energy



## Outputs

Materials/Products

Solid Waste

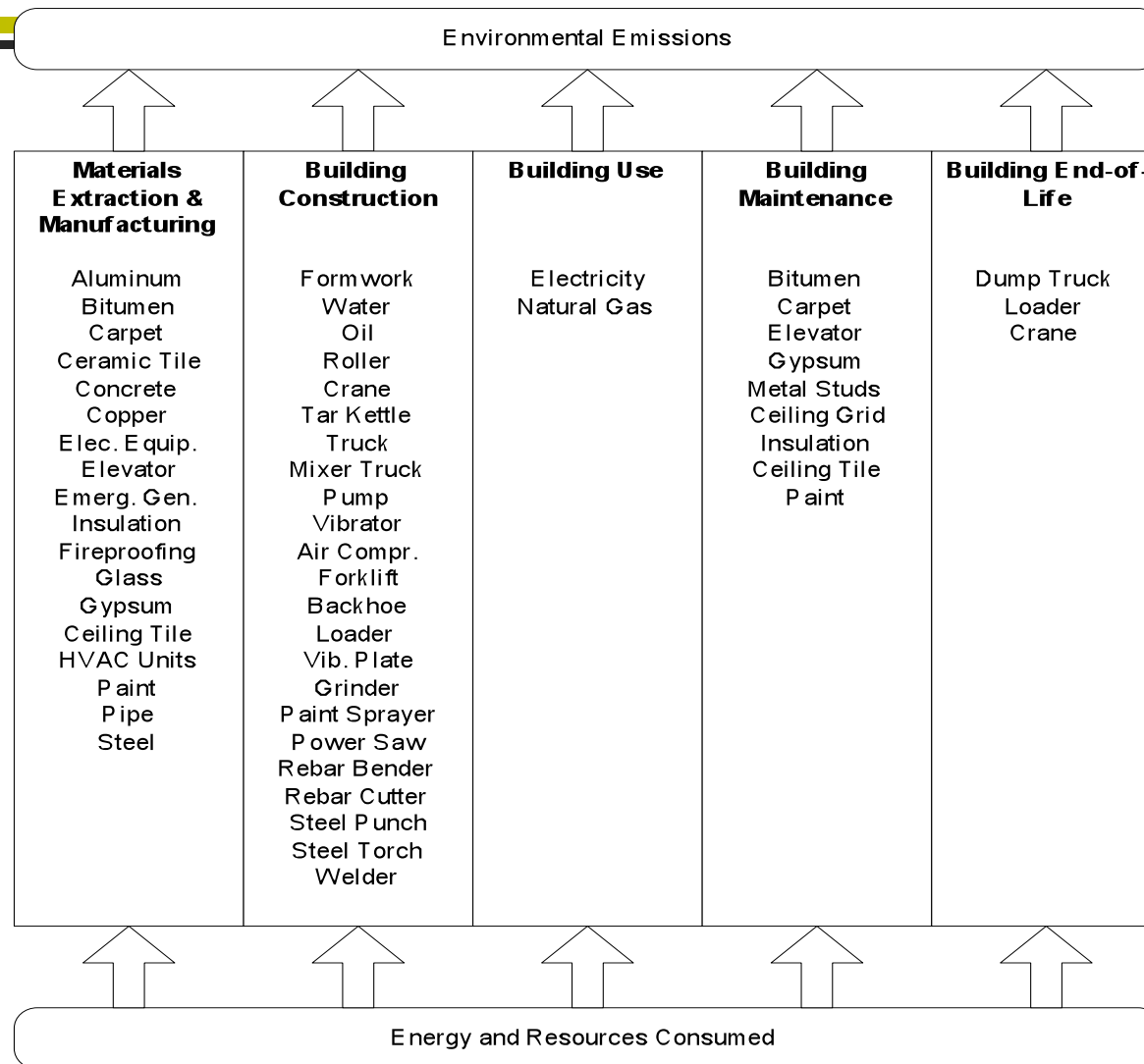
Airborne Emissions

Waterborne Emissions

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# **Buildings**

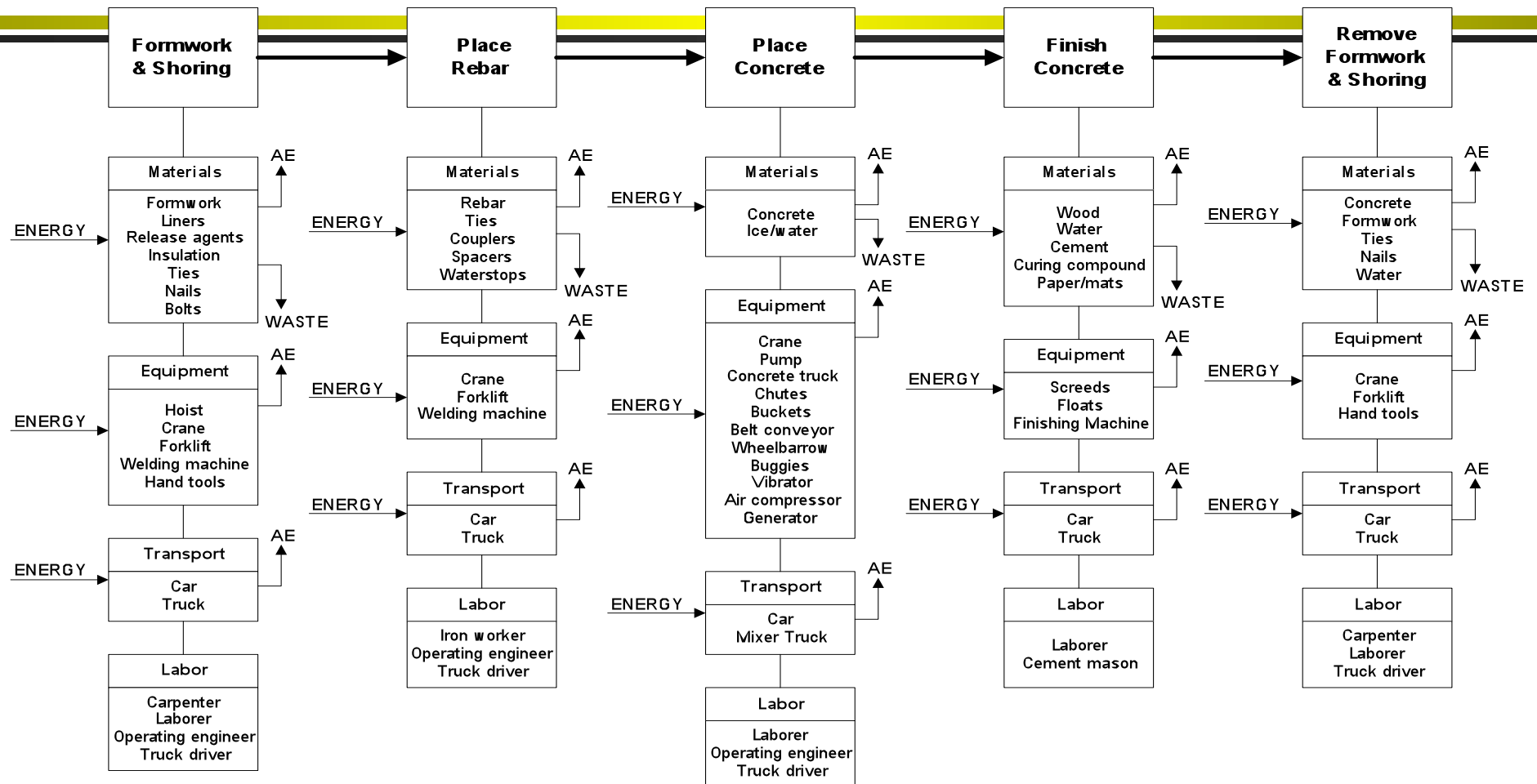
# Commercial Building Life-cycle Assessment



## General Concrete Process

### LEGEND

Activity      Air impact  
                  Land impact  
 AE      = VOC, CO, CO<sub>2</sub>  
                  SO<sub>2</sub>, NO<sub>x</sub>, PM  
 Waste = solid and/or liquid



Source: Guggemos, A. A. (2003). "Environmental Impacts of On-site Construction Processes: Focus on Structural Frames." Unpublished Ph.D. Dissertation, Department of Civil and Environmental Engineering, University of California, Berkeley.

# The Importance of Life-cycle Phases

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- For an average office building (in Finland), ~75% of life-cycle (50 yrs) CO<sub>2</sub> emissions are accounted for by electricity consumption and heating.
- But ~80% of life-cycle VOC emissions are due to construction materials production and building maintenance.

(Source: Seppo Junnila, "Comprehensive LCA Reveals New Critical Aspects in Offices," Proceedings of *Sustainable Building 2002 Conference*, Oslo, September 2002)

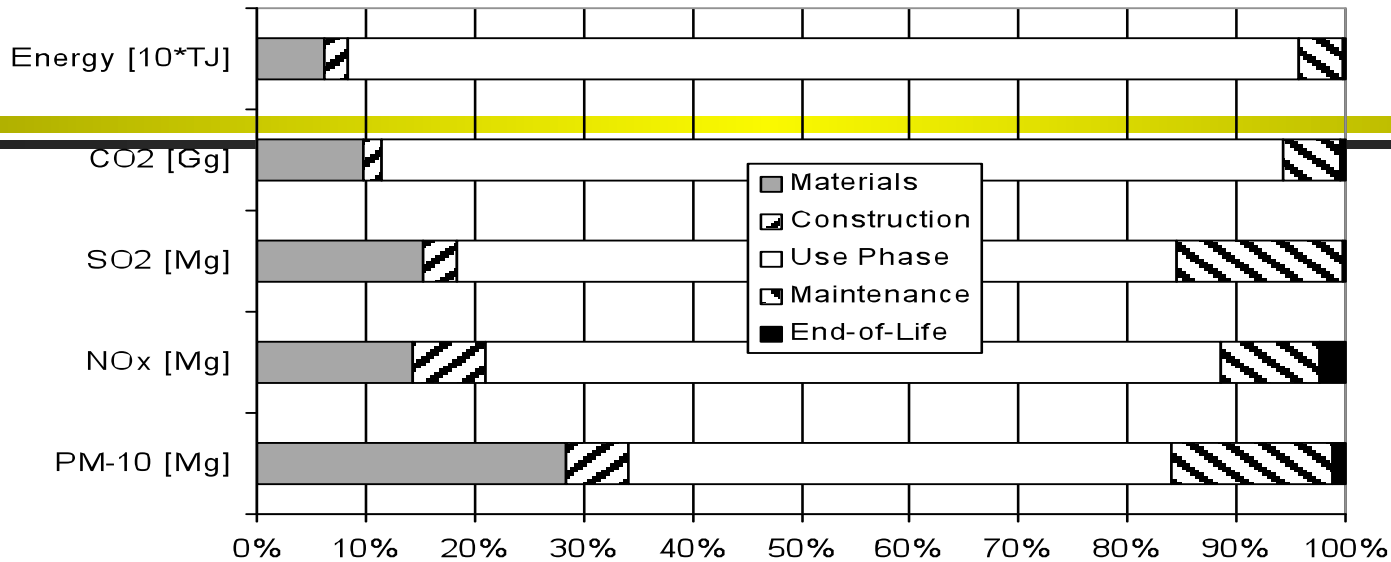


# European – U.S. Office Building Comparison

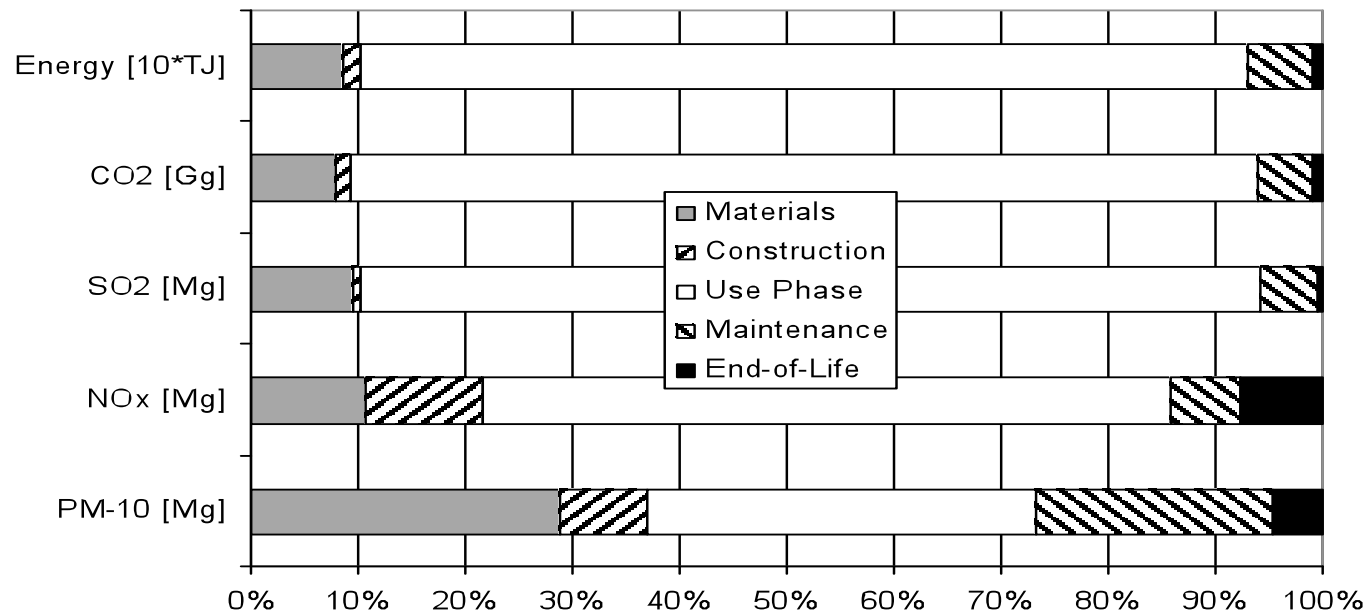
- Located in Southern Finland / Midwest U.S.
- Typical 4-story / 5-story building; 4,400 m<sup>2</sup> area;  
17,300 m<sup>3</sup> / 16,400 m<sup>3</sup> volume
- Structural frame:
  - » pre-fabricated concrete elements, sandwich-panels
  - » steel-reinforced concrete beam-column system, shear walls at core
- Exterior envelope: brick veneer on concrete / aluminum curtain wall
- Interior finishes: typical commercial office space
- Construction materials: 1,190 kg/m<sup>2</sup> / 1,290 kg/m<sup>2</sup>
- Maintenance materials: 240 kg/m<sup>2</sup> / 70 kg/m<sup>2</sup>
- Heat: 36 kWh/m<sup>3</sup>/yr (~average) / Natural gas: 17.5 m<sup>3</sup>/m<sup>2</sup>/yr
- Electricity: 70 kWh/m<sup>2</sup>/yr (30% below average) / 184+56 kWh/m<sup>2</sup>/yr
- 54 different building elements consisting of 23 different building materials
- Service life: 50 years

# Comparison of Contribution of Life-cycle Phases

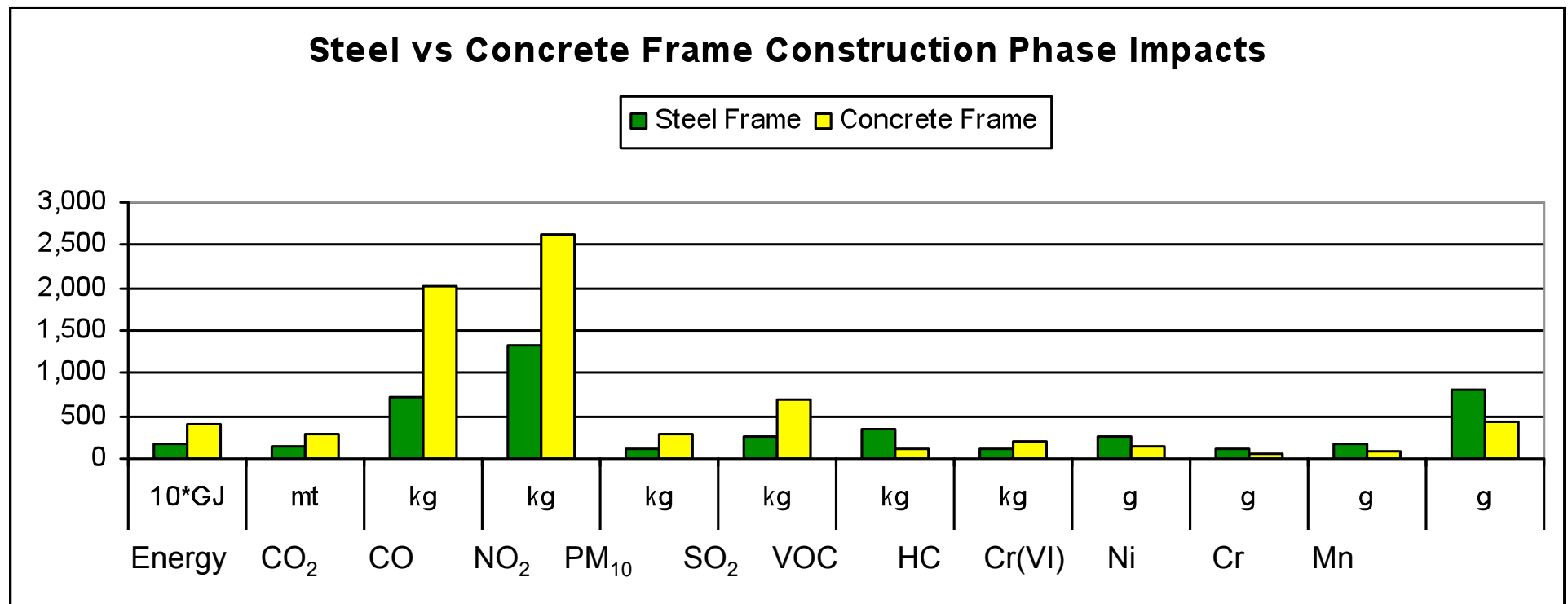
Finland



U.S.



# Steel vs. Concrete Frame: Construction Phase Effects (Frame Only)



Source: Guggemos, A. A., and Horvath, A. "Comparison of Environmental Effects of Steel- and Concrete-Framed Buildings." *J. of Infrastructure Systems*, June 2005, pp. 93-101.

# State of LCA

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- Too few LCAs exist
- They are too specific to
  - » a problem
  - » a technology
  - » assumptions
  - » a geographic area
  - » a point in time
- Many are incomplete
- No policy should be passed without LCA!