Reuse of Waste CO_2 as a Metalworking Fluid

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Concerns Associated with Metalworking Fluid Use

- **Metalworking Fluids are ubiquitous and necessary**
  - In North America sold ~2 billion gallons in 2000.
  - Up to 12% of metals manufacturing costs

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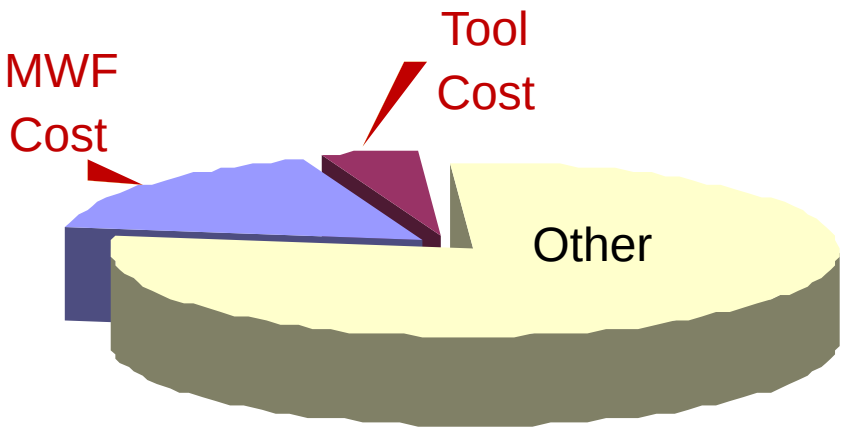
- **Why such large costs?**
  - Purchase: $.20-$1.00/gallon
  - Maintenance: $0.20-$1.20/gallon
  - Disposal: $0.25-$2/gallon



Concerns Associated with Metalworking Fluid Use

- **Hazardous to human health**
  - MWFs, microorganisms, biocides
- **Significant environmental burden**

'Guinea pig' worker wins $28 million from Emerson unit

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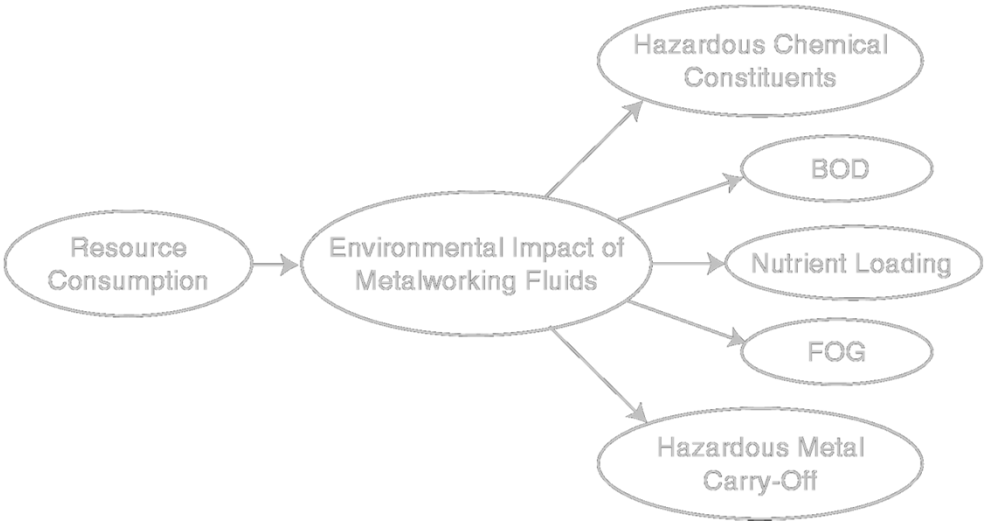
November 24, 2013 11:00 pm • By Jim Gallagher jgallagher@post-dispatch.com > 314-340-8390 0

Enlarge Photo

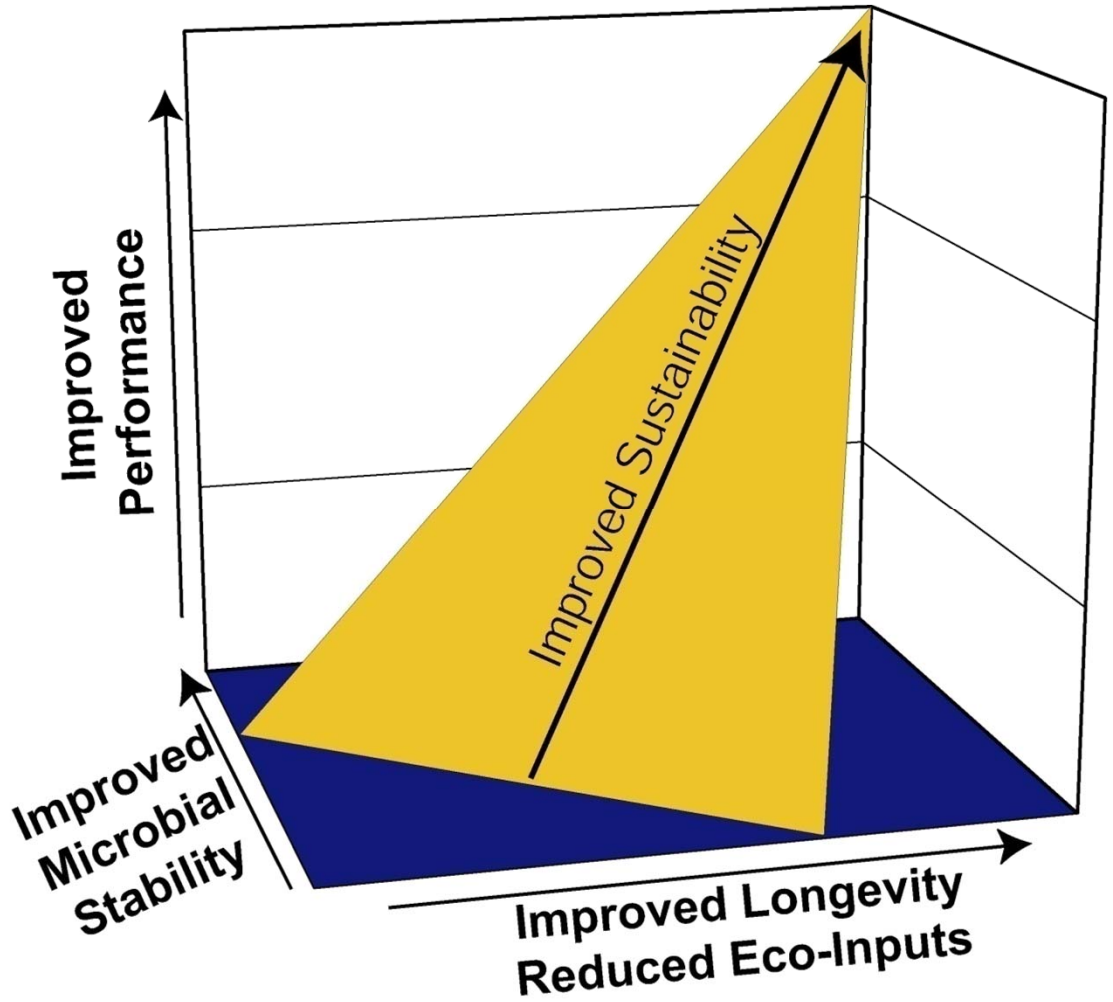
A Laclede County jury has ordered an Emerson subsidiary to pay $28 million to a worker, labeled a "human guinea pig," who claimed he suffered lung damage in the company's Lebanon, Mo., compressor plant.

Emerson called the verdict "preposterous" and pledged an appeal.

Philip Berger, 56, developed inflammation of the lung after breathing contaminants from a chemical used to cool cutting tools, the suit claimed. His lawyer, Kenneth McClain, said Berger began coughing severely after a ventilator failed and a vapor cloud filled his work area.

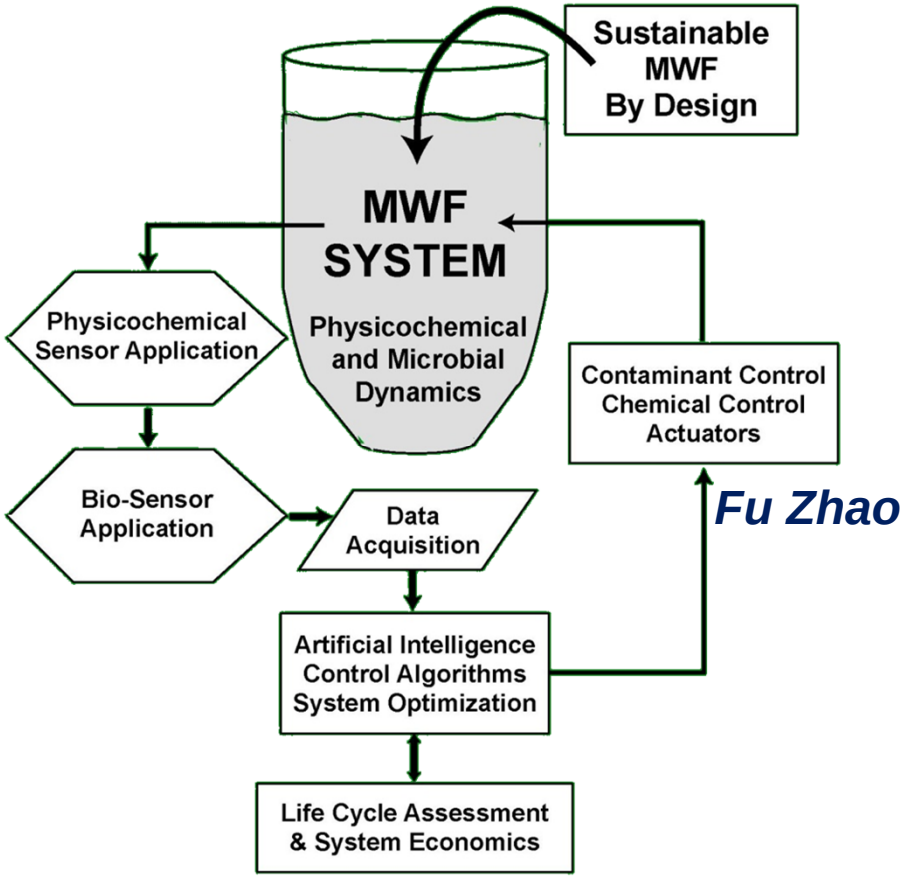


Conceptual Model for Sustainable Metalworking Fluids

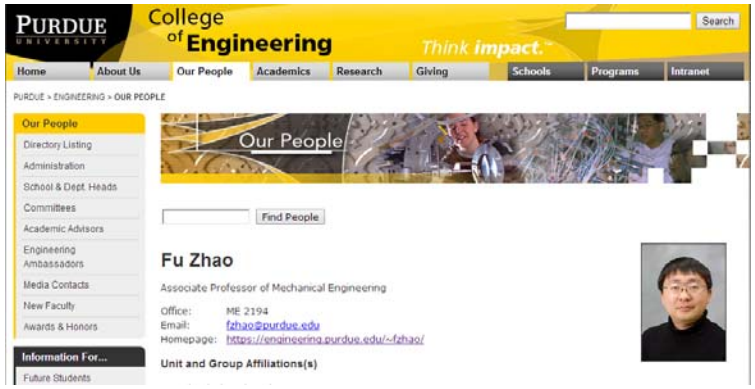


Research Model for Sustainable Metalworking Fluids

Julie Zimmerman

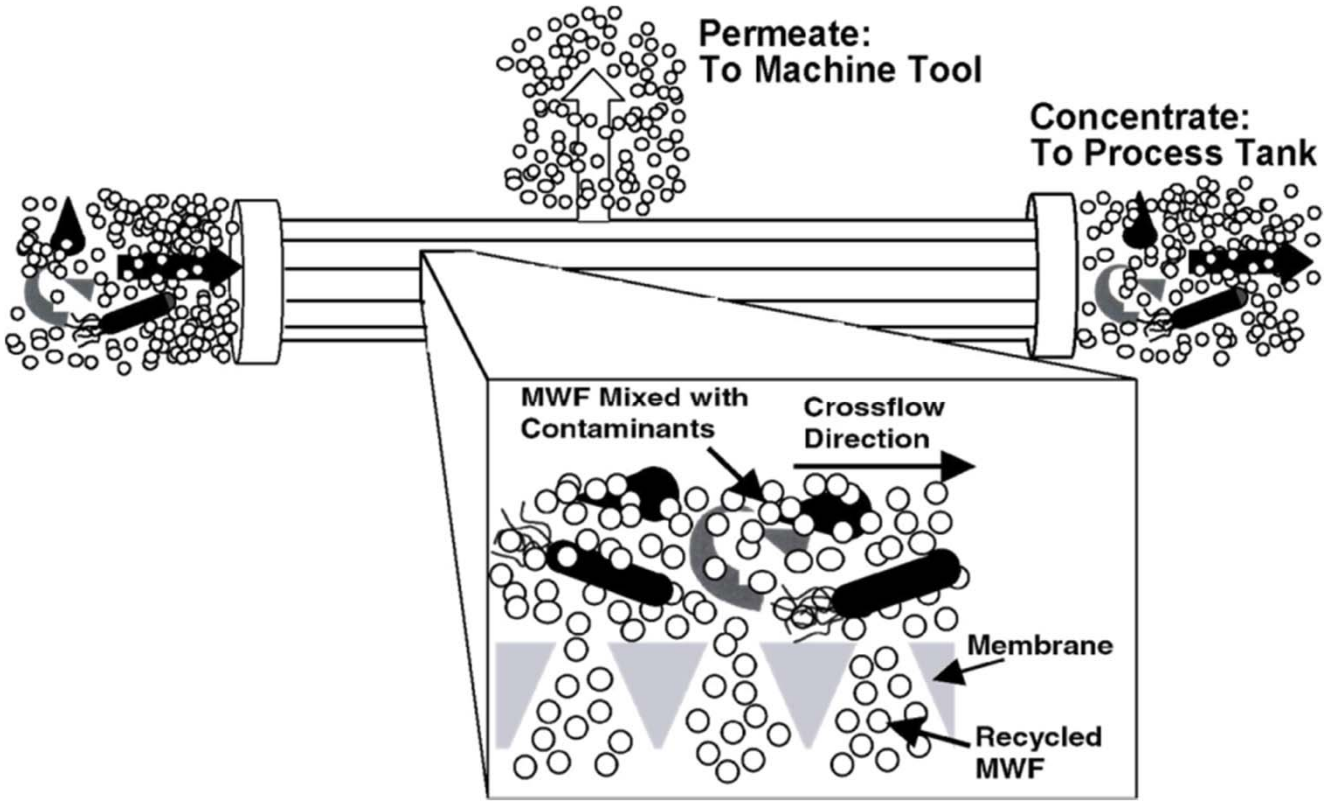


Fu Zhao



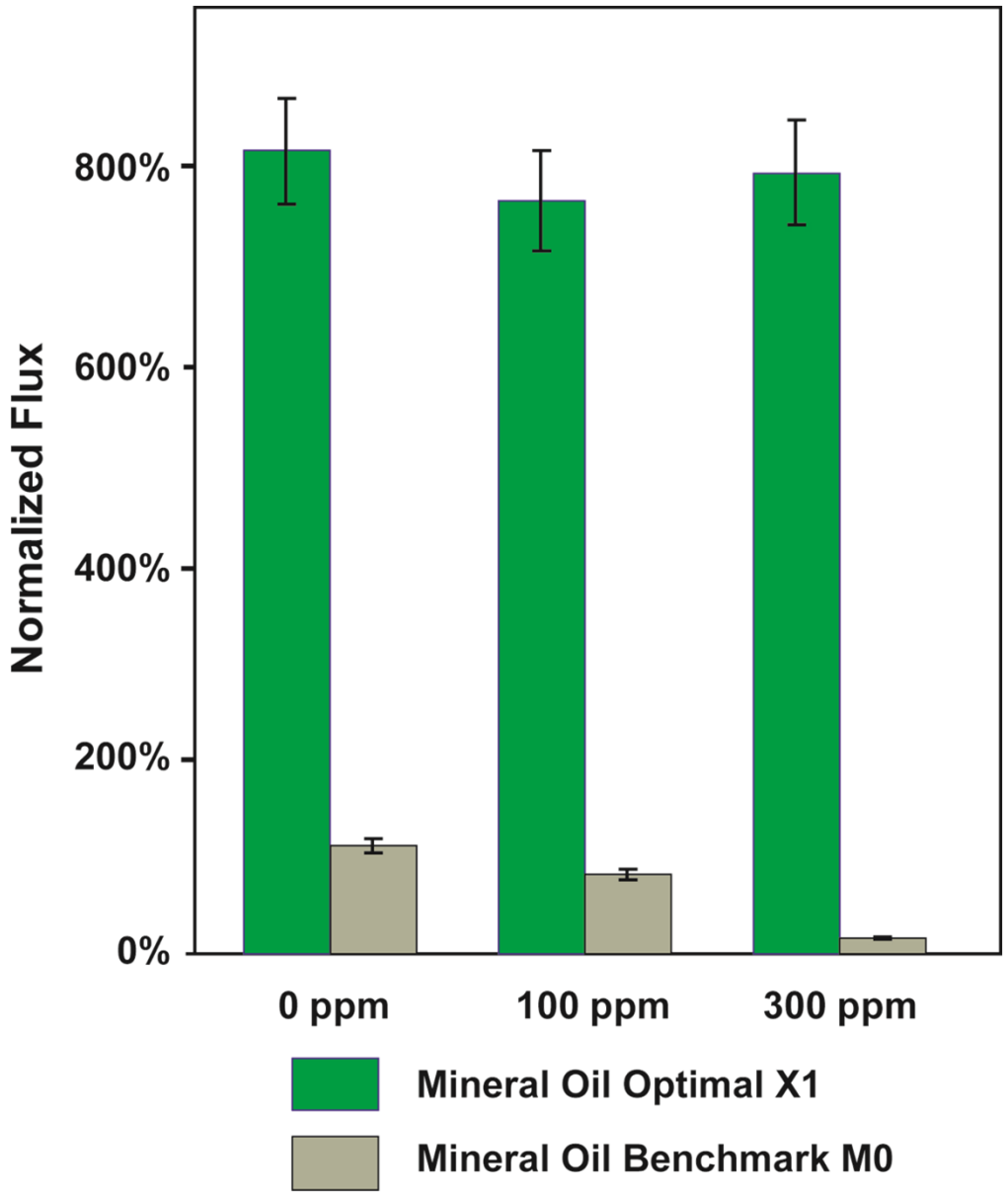
National Science Foundation, "CAREER: Optimization of Metalworking Fluids in Environmentally Benign Manufacturing Systems" (2001-2005)
National Science Foundation, "Minimization of Health Risks due to Metalworking Fluid Microbes and Biocides" (2000-2003)

Microfiltration of Metalworking Fluids

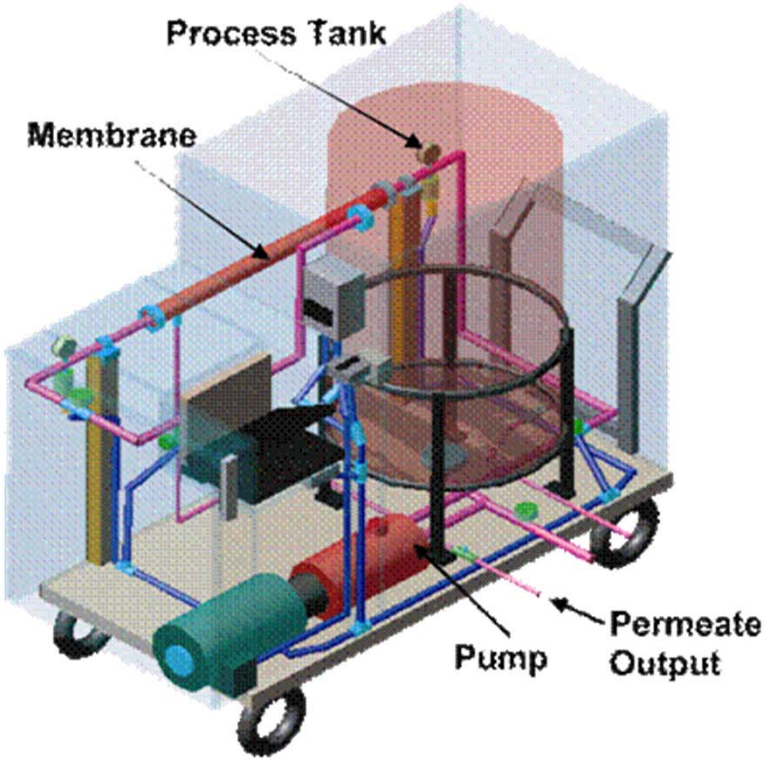


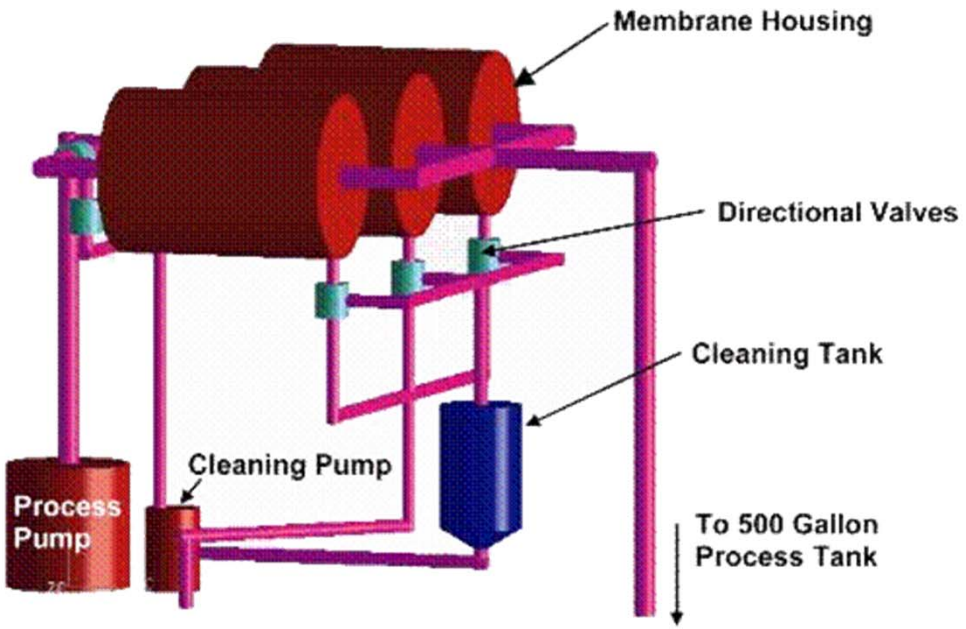
$$J(t) = \frac{\Delta P \; e^{-\left\{\chi \cdot \exp\left(\left[\frac{\theta}{1+\theta}G_1 + \frac{1}{1+\theta}G_2 + \kappa RT\left(\frac{\theta}{1+\theta}\ln\frac{\theta}{1+\theta} + \frac{1}{1+\theta}\ln\frac{1}{1+\theta}\right) - G_0\right]/kT\right)\right\}t}}{R_m}\left[1 - \frac{2 \cdot R^*_{\max} c_o}{\left(k_d / k_a \omega + c_o\right) \cdot d_0}\right]^2$$

Re-Designed Cutting Fluids are More Recyclable and More Stable



Microfiltration Recycling System Pilot Projects





Microfiltration Metalworking Fluid Recycling

Case Studies:

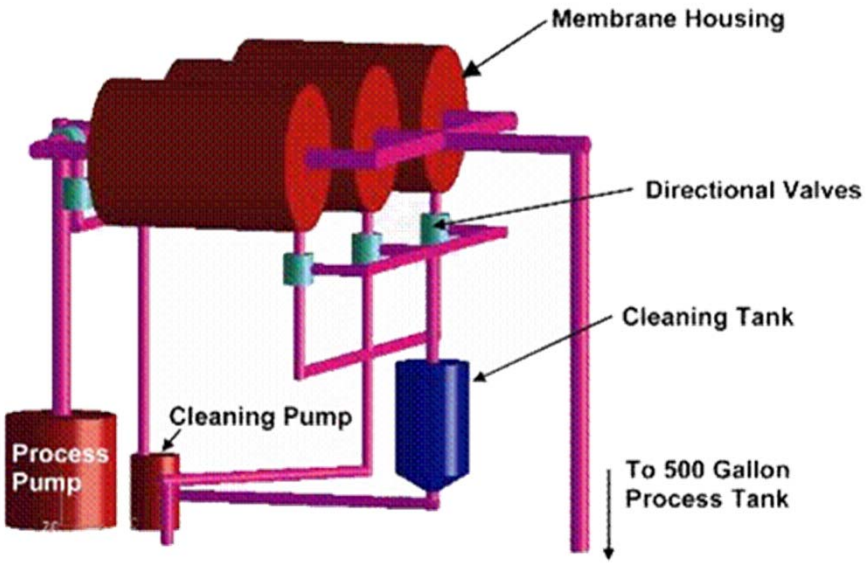
- ***Small aluminum grinding facility: ~$250K per year savings***
- ***Large machinery manufacturer: >$2M per year savings***
- ***Alkaline cleaner recycling: ~$25K per year savings***

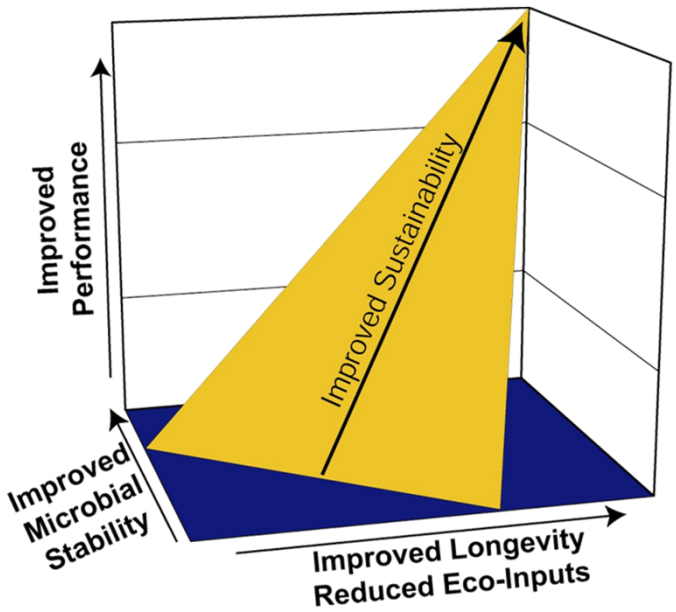
Microfiltration of Metalworking Fluids

- Cost Savings
- Improved Performance & Stability
- Environmental Benefits
- Health & Safety Benefits

BUT:

- No Customers and therefore not sustainable!

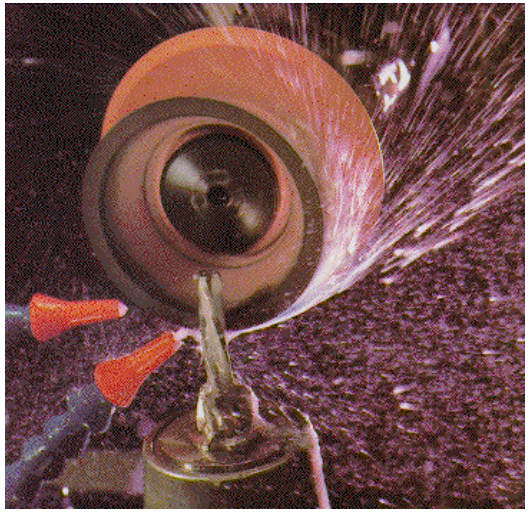




Machining Fluid Improvements

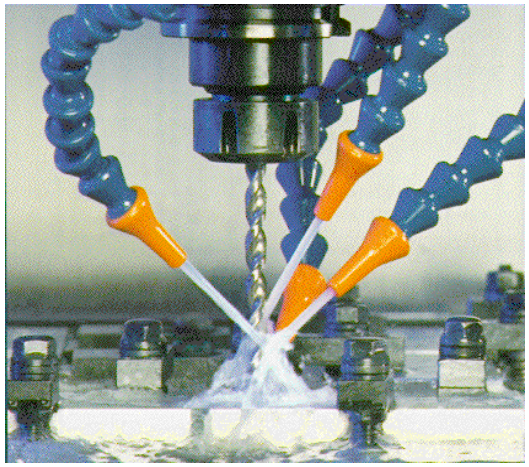
Who cares?

- Workers who get sick
- Environmentalists / U.S. EPA
- Academics



Who doesn't care?

- Most U.S. Manufacturing Engineers
- Most U.S. Lawmakers (today)



Machining Productivity Improvements

Who cares?

- Everyone making a profitable metal product!
- Machining fluids impact: revenue generation rate, tool costs, labor costs, machine tool costs

New Materials = New Machining Challenges

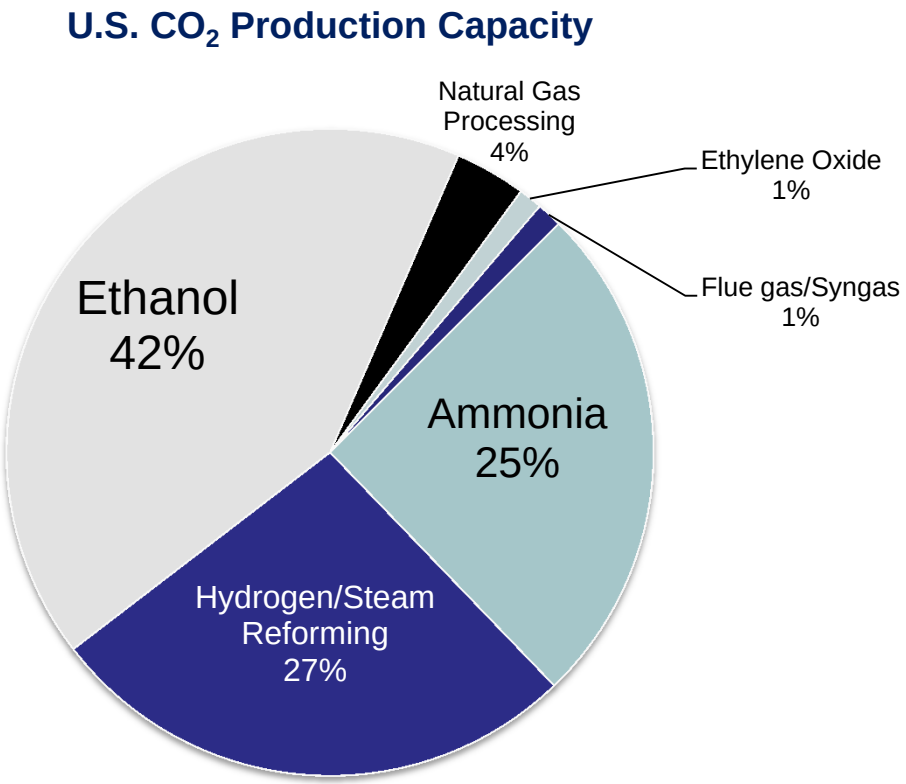
- Automotive: Flex-fuel and clean diesel vehicles
- Aerospace: Titanium and Composites in aircraft
- Industrial Equipment: Fuel efficient construction

Supercritical CO2 MWFs: A New Way

- Tool life increases on “next generation” metalworking operations on the order of 2-4x and/or double the machining speeds.
- As long as equipment is operated safely, existing health hazards to machines will disappear.

National Science Foundation (2006-2010): “Carbon Dioxide Based Metalworking Fluids”

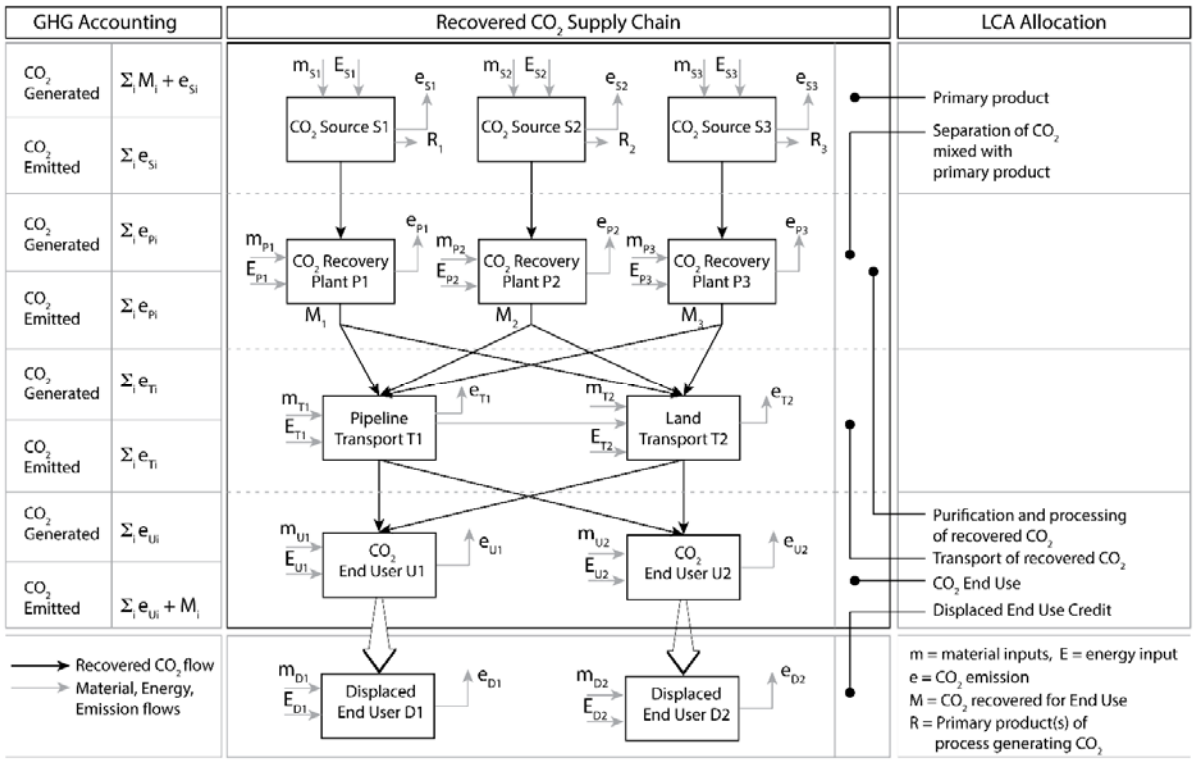
Where does industrial CO_2 come from?



Total Capacity: 10.8 Mt/year
Total Production: 7.7 Mt/year[1]

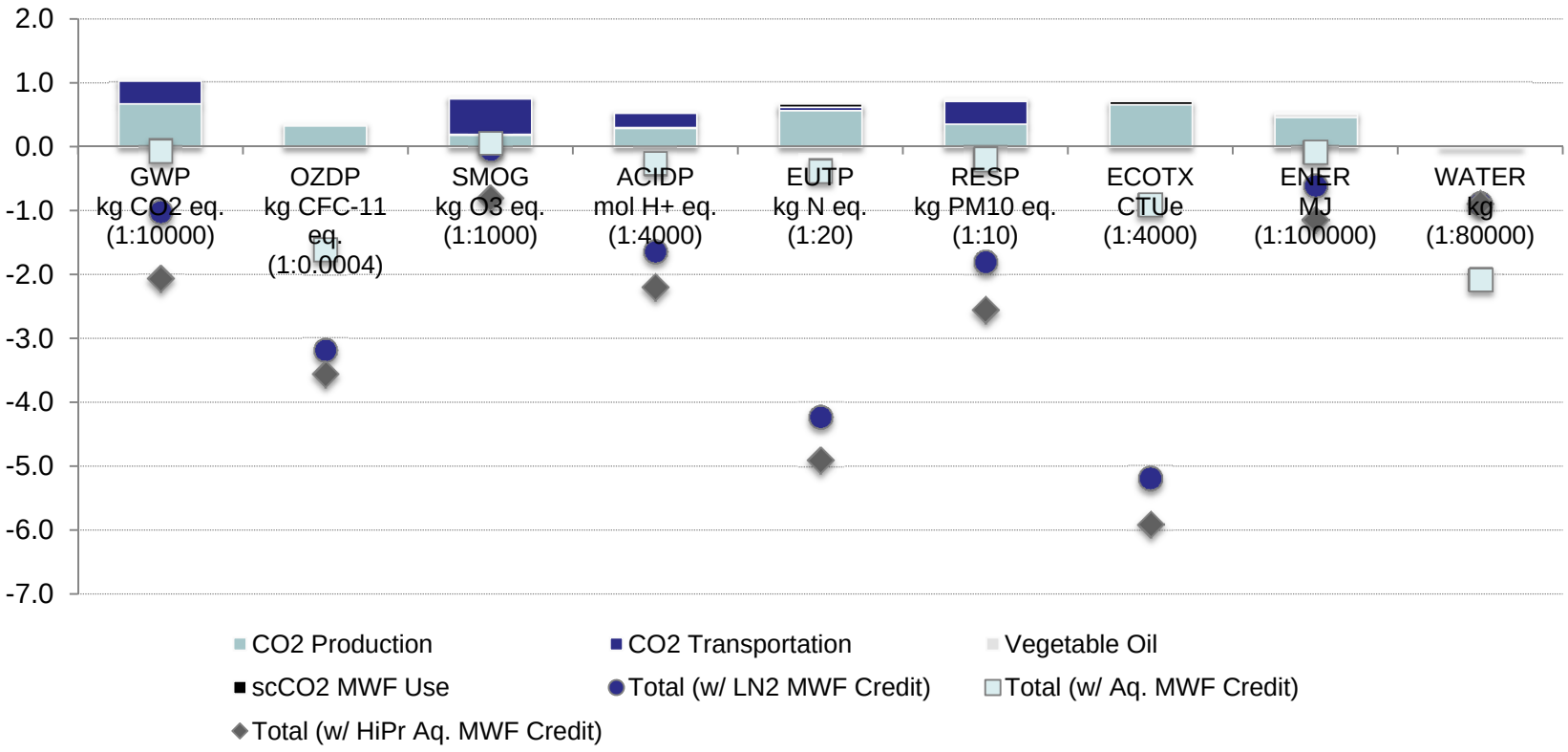
[1] M. Aresta (2003), Carbon Dioxide Utilization: Greening Both the Energy and Chemical Industry: An Overview, ACS Symposium Series, Washington D.C.

Consequential LCA for Estimating CO_2 Separation, Transport, and Application as Metalworking Fluid



National Science Foundation, "Market Driven Emissions from Recovered CO2 Industrial Gas" (2012-2015)

Supercritical CO_2 Reduces Environmental Impact, Health and Safety Concerns, and Improves Performance in Machining



... but will there be customers to make it sustainable?

Lessons Learned Pursuing Sustainable Metalworking Fluids

- Sustainable manufacturing is not just clever technology, or just ability to generate profits, or just environmental improvement, it has social and cultural factors that must be addressed.
- Sustainable manufacturing research must flow from major challenges to solutions rather than from solutions looking for challenges.
- Derivatives of the four NSF grants discussed here generated two start-up companies (Accuri Cytometers and Fusion Coolant Systems), one with over 100 full time employees and large valuation.
    - Successful example of Government-Industry-University contribution to a mutually interesting problem.
    - All three graduated students became successful faculty members.