Energy Impacts of Corrosion

Industrial Opportunities for Energy Savings

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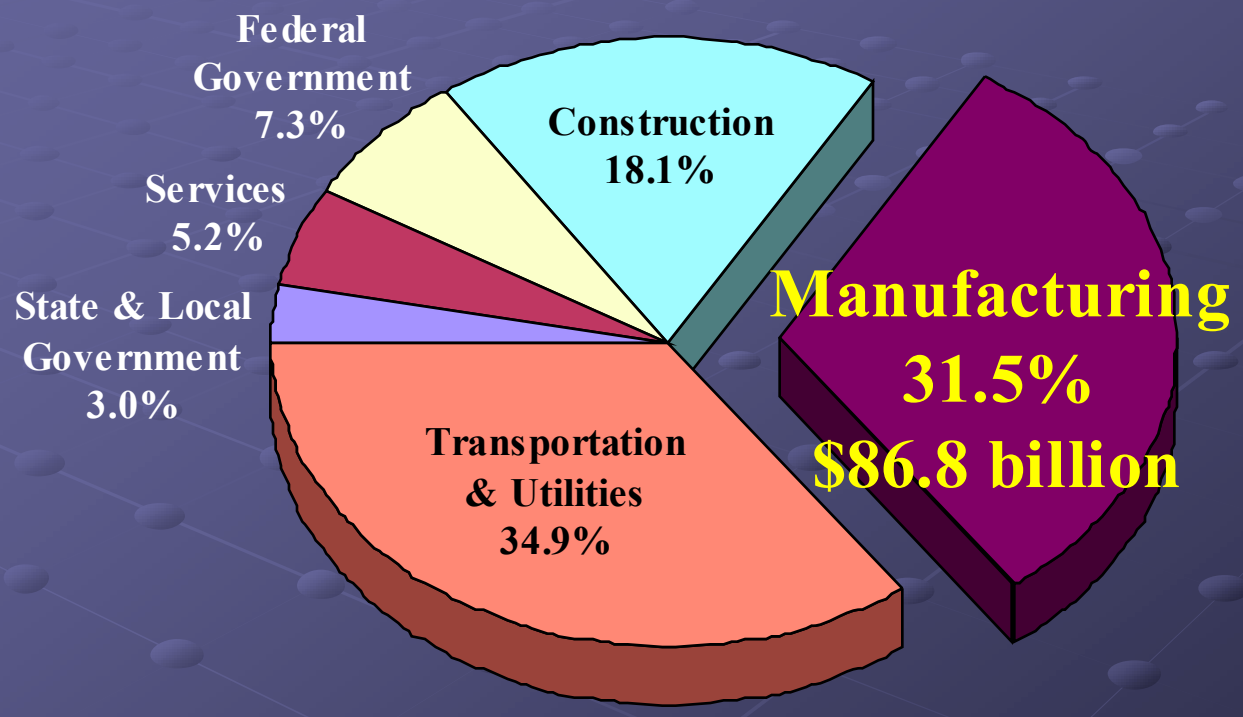
The Corrosion Problem in the United States

- A 2001 study[1] published by NACE International identified the total direct cost of corrosion in the United States as $276 billion per year, or about 3.1% of the GNP.
- Indirect corrosion costs are conservatively estimated to be equal to direct cost, giving a total cost of $552 billion per year.
- Over $121 billion is spent each year on corrosion control chemicals, coatings, and other protective systems.

[1] "Corrosion Cost and Preventative Strategies in the United States", NACE International, 2001

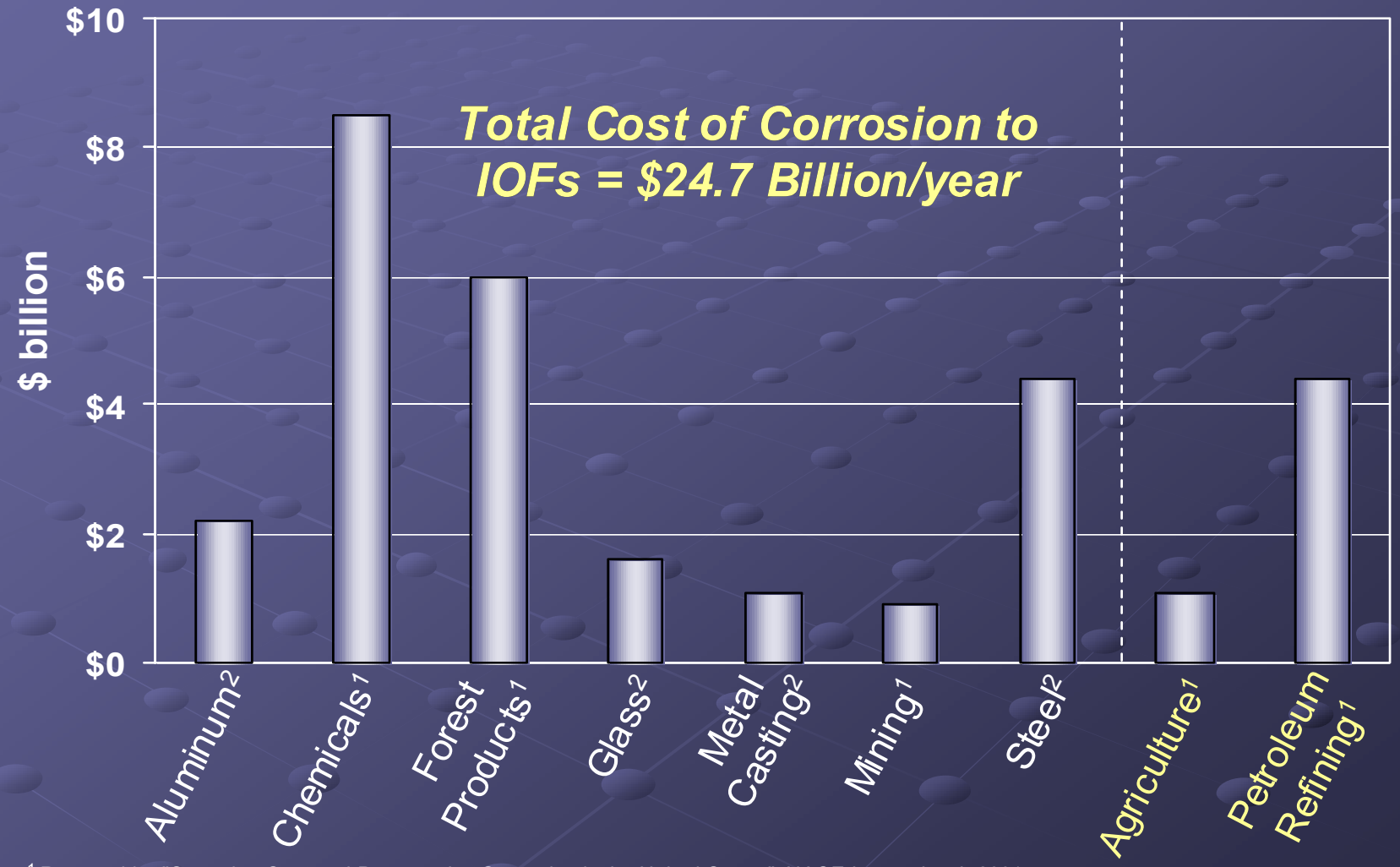
Cost of Corrosion by Sector



Total Direct Corrosion Cost: $276 Billion

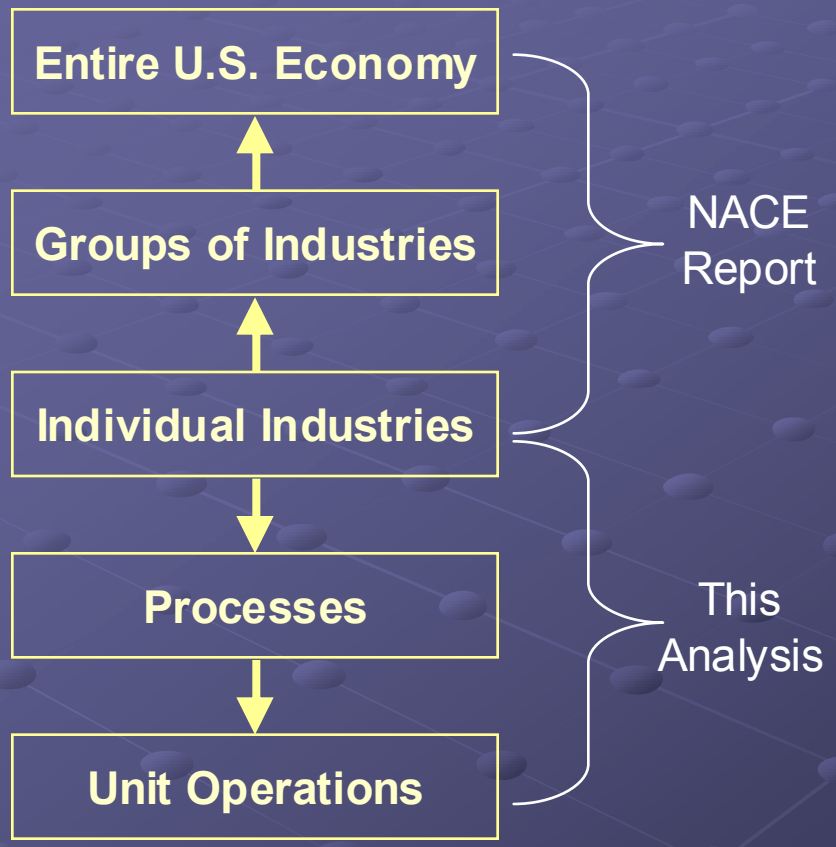
Note: The Manufacturing Sector includes the 'Mining' and 'Agricultural, Forestry, and Fishing' categories.

Estimated Economic Cost of Corrosion to Industries of the Future



[1] Reported by "Corrosion Cost and Preventative Strategies in the United States", NACE International, 2001.
[2] Estimated using NACE Report methodology [corrosion cost is estimated to be 5.87% of GDP].

Why Do We Need Another Study?



$ The NACE study frames the magnitude of corrosion in economic terms.

Btus This analysis seeks to quantify the cost of corrosion in terms of energy. Such analysis must be done using an application-specific, bottoms-up approach.

Specific Opportunities to Reduce the Energy Impact of Corrosion

- We analyzed four environments in the IOFs known to experience significant corrosion:

1. Stress corrosion cracking in Kraft recovery boilers
2. Coking in ethylene furnace tubes
3. Corrosive flue gas from aluminum melting furnaces
4. Metal dusting in various processes such as hydrogen production

Kraft Recovery Boilers: Key Assumptions

- A 2002 RAND case study on Boiler Materials for the Pulp and Paper Industry[1] examines the benefits of implementing new tube materials and better maintenance practices.
- Assumptions include:
  - One-half of plants (~130 plants) adopt better boiler maintenance practices
  - One-half of plants replace their boiler tubes with the new materials
  - Of the plants adopting the new materials, only one-half choose to reduce shutdown days; the other half chose to increase boiler efficiency by an average gain of 0.75%
  - The ¼ of plants who increase boiler efficiency save more energy than the additional energy required by those ¼ plants who increase production, resulting in a net energy savings.

[1]Howell, David R., Richard Silberglitt, RAND and Douglas Norland. "Industrial Materials for the Future R&D Strategies: A Case Study of Boiler Materials for the Pulp and Paper Industry". Prepared for the U.S. Department of Energy, 2003. Available at http://www.rand.org/publications/MR/MR1583/MR1583.pdf.

Energy Impact of Corrosion:

Kraft Recovery Boilers

Barriers

- Many types of corrosion in different regions due to high temperatures, moisture, sulfides, chlorides, and other factors
- Corrosion lowers efficiencies and limits productivity
- SCC in the lower region can lead to emergency shutdowns and smelt-water explosions

Pathways

- Continue research of SCC and other costly corrosion types
- Develop new materials of construction and best operating practices
- Demonstrate and evaluate advanced industrial materials in-service

Critical Metrics

- Understanding of many corrosion types
- Elimination of smelt-water explosions
- Improved boiler performance

Crazed Cracking in 304L Stainless Steel

http://www.babcock.com/pgg/tt/pdf/BR-1668.pdf

Benefits (est.)	Annual Opportunities (2030)
Energy Savings	66.2 trillion Btu
Cost Savings	$73.8 million
Carbon Reduction	0.84 MMTCe

Ethylene Furnace Tubes: Key Assumptions

- 26.9 trillion Btu are based on the impact of condition assessment[1] using the following assumptions:
  - 49 billion lbs of domestic ethylene production
  - 80% of U.S. ethylene furnace market impacted by 2025, and 3% ethylene annual growth rate
  - Constant purchase price for natural gas of $5 per million Btu
  - Energy savings are based on operational changes that lead to an increase in furnace run length, a reduction in coking overlap, and an increase in throughput (yield) by 3%.
- 15.8 trillion Btu are based on the implementation of new tubes that are resistant to coking/carburization and allow for greater heat transfer to the feedstock.
  - 49 billion lbs of domestic ethylene production
  - Furnace energy consumption of 6,450 Btu/lb[2]
  - An improvement in efficiency accounting for 5% energy savings in the furnace.

[1]Pellegrino, Joan, Emory Ford, and Tracy Carole. Impacts of Condition Assessment on Energy Use: Selected Applications in Chemicals Processing and Petroleum Refining. April 2004.

[2]Worrell, Ernst, Dian Phylipsen, Dan Einstein, and Nathan Martin. Energy Use and Energy Intensity of the U.S. Chemical Industry. April 2000. Available at http://www.energystar.gov/ia/business/industry/LBNL-44314.pdf

Energy Impact of Corrosion:

Ethylene Furnace Tubes

Barriers

- Coke formation and deposits on the inner walls of furnace tubes require higher operating temperatures and maintenance shutdowns
- Coke buildup leads to carburization, making tubes and fittings brittle

Pathways

- Continue research of new tube materials
- Research alternative methods of ethylene production
- Demonstrate and evaluate advanced industrial materials and alternative production methods

Critical Metrics

- Heat transfer and coke-resistant capabilities of new tube materials
- Downstream effects of increased throughput in furnace

Construction of Six Modern Ethylene Furnaces

http://www.oit.doe.gov/chemicals/factsheets/intermetallic.pdf

Benefits (est.)	Annual Opportunities (2030)
Energy Savings	42.7 trillion Btu
Cost Savings	$195 million
Carbon Reduction	0.51 MMTCe

Recuperators in Aluminum Furnaces: Key Assumptions

- 19.8 million tons of aluminum are melted each year.[1]
- Gross energy usage in the melting of secondary aluminum is 2.79 kWh/kg (includes transmission and distribution losses).[1]
- Assumption: implementation of recuperators that could sustain corrosive conditions in melting operations would result in 20% energy savings (conservative).[2,3]
- Some recuperators are in operation today, but they have not proved economically feasible to justify industry-wide adoption.
- Assumption: half of the energy consumed in aluminum melting can be subject to energy savings from new recuperator technology (conservative).

[1]Choate, William T. and John A. S. Green. "U.S. Energy Requirements for Aluminum Production: Historical Perspective, Theoretical Limits and New Opportunities." Prepared under contract to BCS, Incorporated for the U.S. Department of Energy, Energy Efficiency and Renewable Energy, February 2003.

[2]OIT Project Fact Sheet: "Demonstration of a High-Temperature, Corrosion Resistant Coating for Recuperators." United States Department of Energy Office of Industrial Technologies, October 2001. Available at http://www.oit.doe.gov/nice3/factsheets/alcoa.pdf.

[3]Ottie, Timothy W. *Recuperators in the Aluminum Industry*. Aluminum Industry Energy Conservation Workshop XI Papers, The Aluminum Association, Inc., 1990.

Energy Impact of Corrosion:

Recuperators on Aluminum Furnaces

Barriers

- Corrosion due to impurities, moisture, and high temperature reduces lifetime
- Modifications (alumina coatings, ceramic materials, and fluidized beds) have limitations
- High maintenance costs, high cost for modified materials

Pathways

- Develop new materials of construction or surface treatments
- Demonstrate and evaluate advanced industrial materials and surface treatments in-service

Critical Metrics

- Useful lifetime of recuperators
- Recuperator performance

Corrosion of recuperator tubes drastically reduces their operational lifetime.

http://www.oit.doe.gov/nice3/factsheets/alcoa.pdf

Benefits (est.)	Annual Opportunities (2030)
Energy Savings	17.1 trillion Btu
Cost Savings	$90.5 million
Carbon Reduction	0.25 MMTCe

Energy Impact of Corrosion: Metal Dusting

Failures Attributed to Metal Dusting	
Industry	Damage
Ammonia Synthesis	Sampling nozzles
	Steam reformer tubes
	Secondary reformers
	Transfer line that quenches from 800 to 450°C
	Waste heat boiler tubes
	Ferrules protecting refractory linings in boilers
Methanol Production	Steam reformer tubes
	Waste heat boiler tubes
	Ferrules protecting refractory linings in boilers
Petrochemical	**Natural gas reformers**
	Catalyst regeneration
	Hydro-dealkylation
	Fired heaters
Other industries include heat treating and direct iron ore reduction.	

Source: Metal Dusting: Proceedings of the International Workshop, September 26-28, 2001. Edited by K. Natesan. Argonne National Laboratory, 2001.

Energy Impact of Corrosion: Metal Dusting

- Assumption: the mitigation or elimination of metal dusting saves 1% of total energy consumed in processes where it is known to occur.

	Total Annual Non-Feedstock Energy Consumption (10^{12} Btu/yr)	Potential Energy Savings (10^{12} Btu/yr)
Ammonia[1]	274	2.74
Methanol[2]	53.5	0.535
H_2 production in refineries[3]	69.0	0.690
Total		**3.97**

[1]Energy consumption calculated as the product of ammonia production and the specific energy consumption. Both figures found in Worrell, Ernst, Dian Phylipsen, Dan Einstein, and Nathan Martin. Energy Use and Energy Intensity of the U.S. Chemical Industry. April 2000. Available at http://www.energystar.gov/ia/business/industry/LBNL-44314.pdf

[2]Energy consumption calculated as the product of methanol production and an assumed specific energy consumption. Non-feedstock consumption was assumed to be 30% of feedstock consumption. Production and specific energy consumption figures found in Worrell 2000.

[3]Energy consumption calculated as the product of hydrogen production in refineries and specific energy consumption. Hydrogen production in refineries is assumed to be equal to hydrogen consumption in refineries. Specific energy consumption figure is from a life cycle assessment on natural gas steam reforming. Both figures found in Spath, Pamela L. and Margaret K. Mann. Life Cycle Assessment of Hydrogen Production via Natural Gas Steam Reforming. February 2001. Available at http://www.nrel.gov/docs/fy01osti/27637.pdf

Energy Impact of Corrosion:

Metal Dusting

Barriers

- Corrosion due to metal dusting decreases operational efficiency, wastes energy, and decreases product yield
- Materials must also meet high temperature mechanical strength properties
- Limited knowledge of process variables that influence metal dusting hinders progress

Pathways

- Develop a database on metal dusting degradation as a function of process variables
- Develop new materials of construction resistant to metal dusting

Critical Metrics

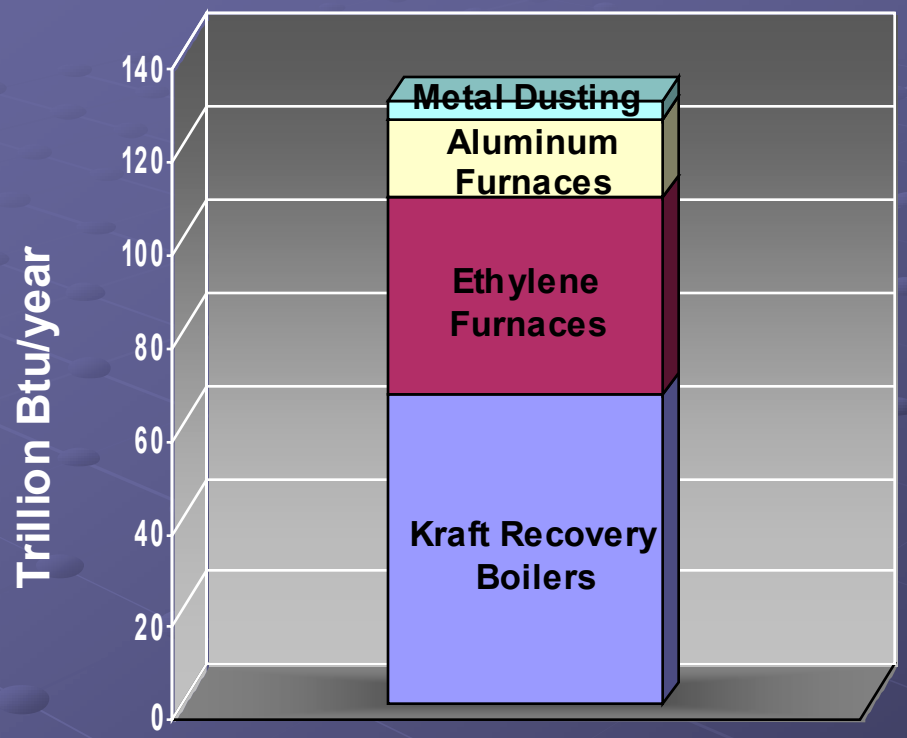
- Resistance to metal dusting and other forms of corrosion at temperatures up to 900ºC
- Mechanical properties at temperatures up to 900ºC

Alloy specimen after exposure at 600°C for 100 hours in a laboratory simulated metal dusting environment, after carbon removal.

http://www.eere.energy.gov/industry/chemicals/pdfs/metaldusting.pdf

Benefits (est.)	Annual Opportunities (2030)
Energy Savings	3.97 trillion Btu
Cost Savings	$21.0 million
Carbon Reduction	0.06 MMTCe

Total Identified Energy Opportunity



Total Identified Impact of Corrosion: 130 Trillion Btu/year

- Conservative estimates; actual energy opportunity is likely higher
- Only four applications are considered; analysis of other processes can be added as desired
- R&D to develop corrosion-resistant materials can yield significant energy savings

Acknowledgements

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