$276 Billion
The United States Cost of Corrosion Study

ANACE
INTERNATIONAL
THE CORROSION SOCIETY
Amendment to the “Transportation Equity Act for the 21st Century (TEA-21)” in 1998 led to this project
Cost of Corrosion - Acknowledgement

- Project Funded By:
  - Federal Highway Administration (DOT)
    - Office of Infrastructure Research and Development
  - Project Manager: Y. Paul Virmani, Ph.D.

- In Cooperation With:
  - NACE International – The Corrosion Society
    - Disseminating study finding – raise awareness
Cost of Corrosion – Study Contractor

- CC Technologies
  - Gerhardus H. Koch, Ph.D.
  - Neil G. Thompson, Ph.D.
  - Michael P.H. Brongers
  - Joe H. Payer, Ph.D., Case Western – Reserve University
Cost of Corrosion – Presentation Outline

• Study Goals
• Previous Studies
• Current Study
  • Method 1 – Corrosion Control Methods & Services
  • Method 2 – Industry Sector Analysis
• Highlights of Selected Sectors
• Extrapolation to Total Corrosion Cost
• Preventative Strategies
Cost of Corrosion – Study Goals

- Determines the cost of corrosion control methods and services
- Determines the cost of corrosion for specific industry sectors
- Extrapolate individual sector costs to a national total corrosion cost
- Assess barriers to progress and effective implementation
- Develop strategies for realizing cost savings
Cost of Corrosion – Previous Studies

- 1950 H.H. Uhlig – US Study: 2.1% of GNP
- 1970 T.P. Hoar – UK Study: 3.5% of GNP
- 1974 Japan Study: 1.2% of GNP
- 1975 Battelle/NBS – U.S. Study: 4.5% of GNP
Cost of Corrosion – Method 1 – Methods & Services

- All costs are direct corrosion costs
- Disadvantage: many costs are missed
  - Costs of labor attributed to corrosion management activities
  - Cost of the equipment required because of corrosion-related activities
  - Loss of revenue due to disruption in supply of product
  - Cost of loss of reliability
## Cost of Corrosion – Method 1 – Methods & Services

<table>
<thead>
<tr>
<th>Service</th>
<th>Cost (B$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protective Coatings</td>
<td>108.6</td>
</tr>
<tr>
<td>Corrosion Resistant Alloys</td>
<td>7.7</td>
</tr>
<tr>
<td>Corrosion Inhibitors</td>
<td>1.1</td>
</tr>
<tr>
<td>Engineering Plastics/Polymers</td>
<td>1.8</td>
</tr>
<tr>
<td>Cathodic &amp; Anodic Protection</td>
<td>1.0</td>
</tr>
<tr>
<td>Corrosion Control Services</td>
<td>1.2</td>
</tr>
<tr>
<td>Research &amp; Development</td>
<td>-</td>
</tr>
<tr>
<td>Education &amp; Training</td>
<td>-</td>
</tr>
</tbody>
</table>

**TOTAL:** B$ 121.41
Cost of Corrosion – Method 2 – Industry Sector Analysis

• For each sector, details of analysis are different
  • Government Reports
  • Publicly Available Documents
  • Industry Experts
  • U.S. Department of Commerce Bureau Census
  • Existing Industrial Surveys
  • Trade Organizations
  • Industry Groups
  • Individual Companies
Cost of Corrosion – Method 2 – Industry Sector Analysis

- 26 Sectors in 5 Categories
  - Infrastructure
  - Utilities
  - Transportation
  - Production & Manufacturing
  - Government
Cost of Corrosion – Method 2 – Industry Sector Analysis
Cost of Corrosion – Category: Infrastructure

Highway Bridges: B$ 8.3
Gas & Liquid Transmission Pipelines: B$ 7.0
Waterways & Ports: B$ 0.3
Hazardous Materials Storage: B$ 7.0
Airports: B$ -
Railroads: B$ -

TOTAL: B$ 22.6
Cost of Corrosion – Category: Utilities

<table>
<thead>
<tr>
<th>Category</th>
<th>Amount (B$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas Distribution</td>
<td>5.0</td>
</tr>
<tr>
<td>Drinking Water and Sewer Systems</td>
<td>36.0</td>
</tr>
<tr>
<td>Electrical Utilities</td>
<td>6.9</td>
</tr>
<tr>
<td>Telecommunications</td>
<td>-</td>
</tr>
<tr>
<td><strong>TOTAL:</strong></td>
<td><strong>47.9</strong></td>
</tr>
</tbody>
</table>
Cost of Corrosion – Category: Transportation

<table>
<thead>
<tr>
<th>Category</th>
<th>Cost (B$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motor Vehicles</td>
<td>23.4</td>
</tr>
<tr>
<td>Ships</td>
<td>2.7</td>
</tr>
<tr>
<td>Aircraft</td>
<td>2.2</td>
</tr>
<tr>
<td>Railroad Cars</td>
<td>0.5</td>
</tr>
<tr>
<td>Hazardous Materials Transport</td>
<td>0.9</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>29.7</strong></td>
</tr>
</tbody>
</table>
## Cost of Corrosion – Category: Production & Manufacturing

<table>
<thead>
<tr>
<th>Category</th>
<th>Cost (B$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil &amp; Gas Exploration &amp; Production</td>
<td>1.4</td>
</tr>
<tr>
<td>Mining</td>
<td>0.1</td>
</tr>
<tr>
<td>Petroleum Refining</td>
<td>3.7</td>
</tr>
<tr>
<td>Chemical, Petrochemical, &amp; Pharmaceutical</td>
<td>1.7</td>
</tr>
<tr>
<td>Pulp &amp; Paper</td>
<td>6.0</td>
</tr>
<tr>
<td>Agricultural Production</td>
<td>1.1</td>
</tr>
<tr>
<td>Food Processing</td>
<td>1.1</td>
</tr>
<tr>
<td>Electronics</td>
<td>-</td>
</tr>
<tr>
<td>Home Appliances</td>
<td>1.5</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>17.6</strong></td>
</tr>
</tbody>
</table>
Government

Defense B$ 20.0
Nuclear Waste Storage B$ 0.1

TOTAL B$ 20.1
## Cost of Corrosion – Summary of Sector Analyses

<table>
<thead>
<tr>
<th>Sector</th>
<th>B$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infrastructure</td>
<td>22.6</td>
</tr>
<tr>
<td>Utilities</td>
<td>47.9</td>
</tr>
<tr>
<td>Transportation</td>
<td>29.7</td>
</tr>
<tr>
<td>Production &amp; Manufacturing</td>
<td>17.6</td>
</tr>
<tr>
<td>Government</td>
<td>20.1</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>137.9</strong></td>
</tr>
</tbody>
</table>
Highlights of Selected Sectors

Highways & Bridges
Transmission Pipelines
Drinking Water & Sewer Systems
Oil & Gas Exploration & Production
Highways & Bridges

$8.3 Billion Per Year

$276 Billion
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National Bridge Inventory Database

• Approximately 600,000 bridges in the U.S
  Half were built between 1950 and 1994

• The materials of construction
  Concrete, steel, timber, masonry,
  timber/steel/concrete combinations, & aluminum

• This sector focused on reinforced concrete and steel bridges; they make up
  the vast majority of highway bridges
Highway Bridges – Trends

• Reported downward trend in the % structurally deficient bridges - decrease from 18 % to 15 % between 1995 to 1999

• However, costs to replace aging bridges increased by 12 % during the same period.

• In addition, there has been a significant increase in the required maintenance of the aging bridges
Sector Summary: Highway Bridges

Replace structurally deficient bridges \( \text{B$ 3.79} \)

Maintenance and capital cost
  For concrete bridge decks \( \text{2.00} \)
  For concrete sub- and superstructures \( \text{2.00} \)

Maintenance painting cost for steel bridges \( \text{.5} \)

Total: \( \text{B$ 8.29} \)
Highway Bridges - Findings

Indirect corrosion costs:

• Estimated from life-cycle analysis
• Costs to user due to traffic delays & lost productivity
• More than ten times the direct cost of corrosion
Gas & Liquid Transmission Pipelines

$7 Billion Per Year

The United States Cost of Corrosion Study

$276 Billion
Gas & Liquid Transmission Pipelines

- Over 480,000 Miles of Gas and Liquid Transmission Pipelines

  - Gas Transmission
    - Natural Gas Lines – 328,000 Miles

  - Liquid Transmission Lines
    - Crude Oil Lines – 74,000 Miles
    - Liquid Product Lines – 82,000 Miles

- 60% of These Lines Are Over 40 Years
Gas & Liquid Transmission Pipelines

Pipelines

Oil & Gas

Natural Gas
2,000K miles

Transmission
300K miles

Distribution
1,700K miles

Gathering
28K miles

Hazardous Liquids
156K miles

Transmission
135K miles

Crude Oil
53K miles

Liquid Products
82K miles

Gathering
21K miles

Production

Facilities

Oil & Gas

Production

Facilities
Gas & Liquid Transmission Pipelines

• **Typical Corrosion Related Costs**
  - Annual ICCP System Investment - $40 Million
  - Annual Sacrificial CP Investment - $9 Million
  - Annual O&M Costs - $2.4 Billion - $4.8 Billion

• **Certification**
  - 30% of Companies has personnel dedicated to Corrosion Control
  - Regulations require Certification of Corrosion Control Staff
  - Annual Cost $32.4 Million
## Sector Summary: Transmission Pipelines

<table>
<thead>
<tr>
<th></th>
<th>Low Estimate</th>
<th>High Estimate</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>($ x M)</td>
<td>($ x M)</td>
<td>($ x M)</td>
</tr>
</tbody>
</table>
| Cost of Capital                | 2,500        | 2,840         | 2,670   | 38%
| Operations & Maintenance (O&M)| 2,420        | 4,840         | 3,630   | 52%
| Cost of Failures (Non-Related O&M)| 471  | 875          | 673     | 10%
| TOTAL COST DUE TO CORROSION    | 5,391        | 8,555         | 6,973   | 100%
Drinking Water & Sewer Systems

$36 Billion Per Year

$276 Billion

The United States Cost of Corrosion Study
Drinking Water & Sewer Systems

- **Two Separate Systems**
  - Drinking Water
  - Sewage Water

- Costs in Operation, Maintenance, Finance, Capital Investments
- Maintenance crews find and repair leaks, but the number of leaks increases with system age.
Drinking Water & Sewer Systems

• **System Size**
  - 550 liters of water consumption per person per day
  - 56.7 Billion m³ / year in the U.S.
  - 1.4 Million km of municipal water pumping

• A major barrier to progress in corrosion management is the absence of complete and up-to-date information on all water systems.
Operation & Management Costs

• There are only 2 reasons why utilities replace or change water systems:
  • Pipes are considered broken,
    • Leaking water
    • Corrosion products in the water
  • Capacity too small for the area

• Assume 50% of all operation and maintenance costs are corrosion-related
Annual Number Of Water Main Breaks From 1969 To 1997, Example: City of Columbus, OH

- **Actual Water Main Breaks**
- **Predicted Water Main Breaks**

Year:
- 1969
- 1970
- 1971
- 1972
- 1973
- 1974
- 1975
- 1976
- 1977
- 1978
- 1979
- 1980
- 1981
- 1982
- 1983
- 1984
- 1985
- 1986
- 1987
- 1988
- 1989
- 1990
- 1991
- 1992
- 1993
- 1994
- 1995
- 1996
- 1997
- 1998

**Water Main Breaks**
- 253
- 305
- 315
- 319
- 353
- 425
- 408
- 438
- 563
- 509
- 551
- 566
- 537
- 549
- 565
- 646
- 686
- 637
- 665
- 667
- 672
- 753
- 758
- 753
- 653
- 600
- 580

The graph shows the annual number of water main breaks from 1969 to 1997, with a trend line indicating a predicted increase.
Three Reports on Water System Costs

- **1997 EPA**: B$6.9 per year
  - Drinking water system maintenance only

- **1998 AWWA**: B$16.3 per year
  - Drinking water transmission – maintenance only

- **2000 WIN**: B$51 per year for Drinking Water
  - B$45 per year for Sewer Systems

- Includes Operation, Maintenance, Finance, Capital
Cost of Lost Water

- Nationwide, 15% of treated water is lost
- Loss of revenue: B$3.0 per year
- More than 90% of lost-water cost is corrosion-related, because of leaking systems
- Underground leaks go unnoticed: Therefore low cost awareness
Sector Summary: Drinking Water & Sewer Systems

- Operation, Maintenance, Finance, Capital
  - Drinking water systems: B$19.25
  - Sewer systems: B$13.75
  - Cost of Lost water: B$3.0

  TOTAL: B$36.0
Oil & Gas
Exploration Production

$1.4 Billion Per Year

$276 Billion
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Background

- Significant available onshore oil & gas reserves have been explored
- U.S. 1998 Oil Production – 3.04 Billion Barrels
- Recoverable Reserves
  - Deep Waters Offshore
  - Remote Arctic Locations
  - Reservoirs with Unconsolidated Sands
Background

• Relative High Costs of Oil & Gas Production in the U.S.
  • Maintenance Costs Must be Kept to a Minimum
  • Emphasis on Controlling Internal Corrosion with Corrosion Inhibitors
Sector Summary: Oil & Gas

- Operation, Maintenance, Finance, Capital
  - Surface Piping & Facility Costs: M$589
  - Downhole Tubing Expenses: M$463
  - Capital Expenses: M$320

  TOTAL: B$1.36
How to Extrapolate the Total Cost of Corrosion

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Linear Extrapolation of Direct Corrosion Costs

Linear Extrapolation:
BS500.5 at 100% of GDP

BS137.9 at 27.55% of GDP
Non-Linear Extrapolation of Direct Corrosion Costs

Cost Of Corrosion, $x billion

% Of GDP

Non-Linear Extrapolation: BS275.7 at 100% of GDP
BS137.9 at 27.55% of GDP

Analyzed

Extrapolated
Total Cost of Corrosion

- Estimated Cost: B$138
- Extrapolated Cost: B$276
- Actual Cost: >B$550
- Bridges: >5 times
- Electric Utilities: >3 times
Total Direct Cost of Corrosion in the U.S.
B$276 / year = 3.1% of GDP

1998 U.S. GDP
B$8,790
Extrapolated Corrosion Costs: $276 billion, 3.1% of GDP

- State and Local Government, 3.0% $8.3 Billion
- Transportation and Utilities, 34.9% $96.2 Billion
- Federal Government, 7.3% $20.1 Billion
- Construction, 18.1% $50.0 Billion
- Manufacturing, 31.5% $86.8 Billion
- Services, 5.2% $14.3 Billion
Services, 20.9%
Finance, Insurance and Real Estate, 19.2%
Manufacturing, 16.3%
Retail Trade, 9.1%
State and Local Government, 8.5%
Transportation and Utilities, 8.3%
Wholesale Trade, 7.0%
Construction, 4.3%
Federal Government, 4.1%
Mining, 1.2%
Agriculture, 1.5%
Extrapolated Corrosion Costs: $276 billion, 3.1%
Federal Government, 4.1%
Wholesale Trade, 7.0%
Construction, 4.3%
Transportation and Utilities, 8.3%
State and Local Government, 8.5%
Retail Trade, 9.1%
Manufacturing, 16.3%
Finance, Insurance and Real Estate, 19.2%
Non-Technical Preventive Strategies (4)

- Increase awareness of the large corrosion costs and potential savings
- Change the misconception that nothing can be done about corrosion
- Change policies, regulations, standards, and management practices to increase corrosion savings
- Improve education and training of staff
Technical Preventive Strategies (3)

- Advance design practices for better corrosion management
- Advance life prediction and performance assessment methods
- Advance corrosion technology through research, development, and implementation
Further Information

- FHWA – RD-01-156 – Full Report
- FHWA – RD-01-157 – Tech Brief

Contact:
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- Y. Paul Virmani (202) 493-3052

Web Site:
- http://www.corrosioncost.com
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