$276 Billion

The United States Cost of Corrosion Study

SIXTY YEARS
of SERVICE
1941 – 2003

NACE® INTERNATIONAL
THE CORROSION SOCIETY

Cost of Corrosion - Acknowledgement

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

Protective Coatings		B$	108.6
Corrosion Resistant Alloys		B$	7.7
Corrosion Inhibitors		B$	1.1
Engineering Plastics/Polymers		B$	1.8
Cathodic & Anodic Protection		B$	1.0
Corrosion Control Services		B$	1.2
Research & Development		B$	-
Education & Training		B$	-
	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

Gas Distribution		B$	5.0
Drinking Water and Sewer Systems		B$	36.0
Electrical Utilities		B$	6.9
Telecommunications		B$	-
	TOTAL:	B$	47.9

Cost of Corrosion – Category: Transportation

Motor Vehicles		B$	23.4
Ships		B$	2.7
Aircraft		B$	2.2
Railroad Cars		B$	0.5
Hazardous Materials Transport		B$	0.9
	TOTAL:	B$	29.7

Cost of Corrosion – Category: Production & Manufacturing

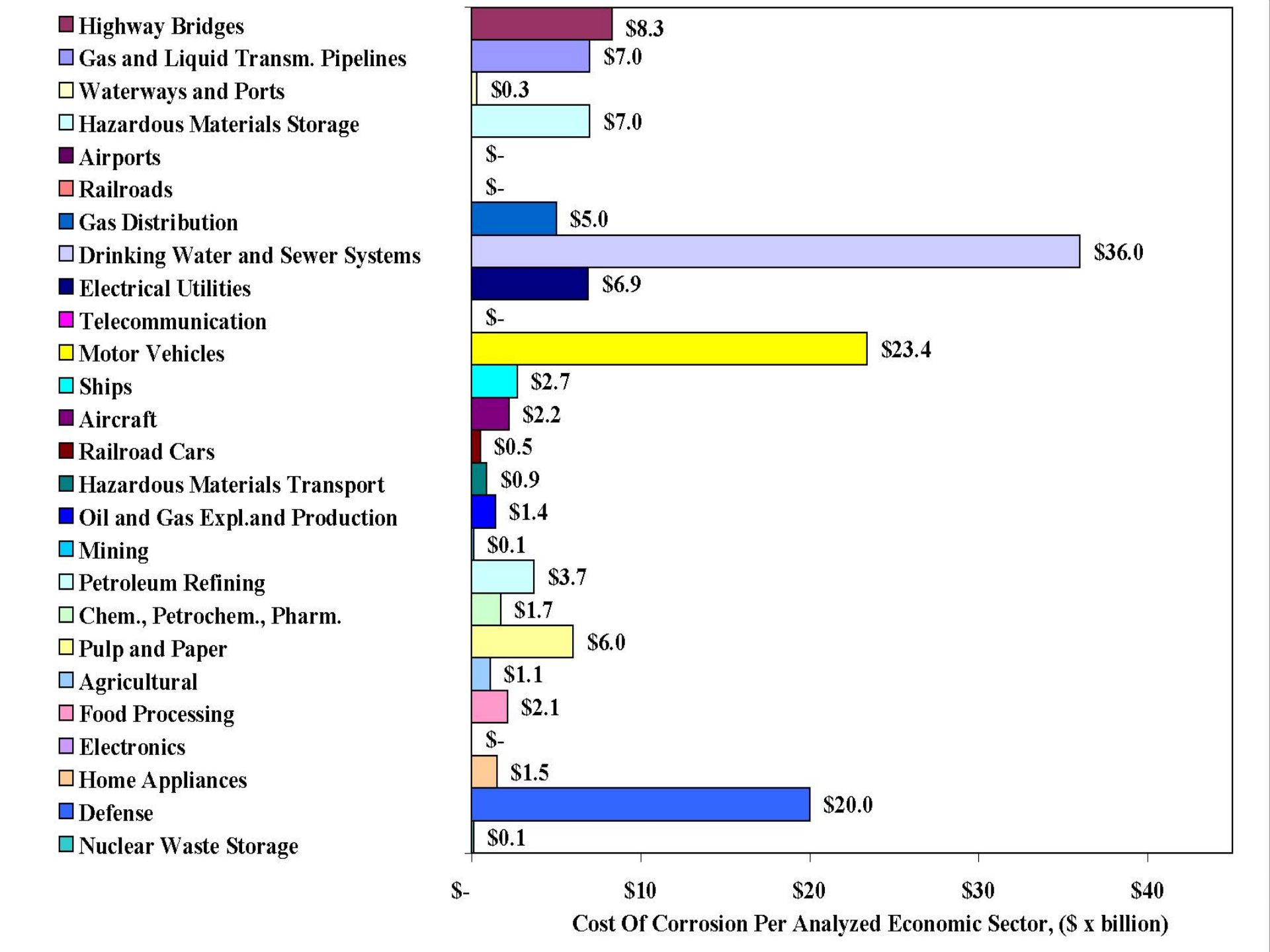
Oil & Gas Exploration & Production		B$	1.4
Mining		B$	0.1
Petroleum Refining		B$	3.7
Chemical, Petrochemical, & Pharmaceutical		B$	1.7
Pulp & Paper		B$	6.0
Agricultural Production		B$	1.1
Food Processing		B$	1.1
Electronics		B$	-
Home Appliances		B$	1.5
	TOTAL	B$	17.6

Government

Defense		B$	20.0
Nuclear Waste Storage		B$	0.1
	TOTAL	B$	20.1

Cost of Corrosion – Summary of Sector Analyses

Infrastructure		B$	22.6
Utilities		B$	47.9
Transportation		B$	29.7
Production & Manufacturing		B$	17.6
Government		B$	20.1
	TOTAL	B$	137.9


Highway Bridges
Gas and Liquid Transm. Pipelines
Waterways and Ports
Hazardous Materials Storage
Airports
Railroads
Gas Distribution
Drinking Water and Sewer Systems
Electrical Utilities
Telecommunication
Motor Vehicles
Ships
Aircraft
Railroad Cars
Hazardous Materials Transport
Oil and Gas Expl.and Production
Mining
Petroleum Refining
Chem., Petrochem., Pharm.
Pulp and Paper
Agricultural
Food Processing
Electronics
Home Appliances
Defense
Nuclear Waste Storage
$8.3
$7.0
$0.3
$7.0
$-
$-
$5.0
$36.0
$6.9
$-
$23.4
$2.7
$2.2
$0.5
$0.9
$1.4
$0.1
$3.7
$1.7
$6.0
$1.1
$2.1
$-
$1.5
$20.0
$0.1
$-
$10
$20
$30
$40
Cost Of Corrosion Per Analyzed Economic Sector, ($ x billion)

Highlights of Selected Sectors

Highways & Bridges

Transmission Pipelines

Drinking Water & Sewer Systems

Oil & Gas Exploration & Production

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Highways & Bridges

$8.3 Billion Per Year

SIXTY YEARS
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1941 – 2003

$276 Billion

The United States Cost of Corrosion Study

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	B$ 3.79	
Maintenance and capital cost		
For concrete bridge decks		2.00
For concrete sub- and superstructures	2.00	
Maintenance painting cost for steel bridges	.5	
	Total : 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

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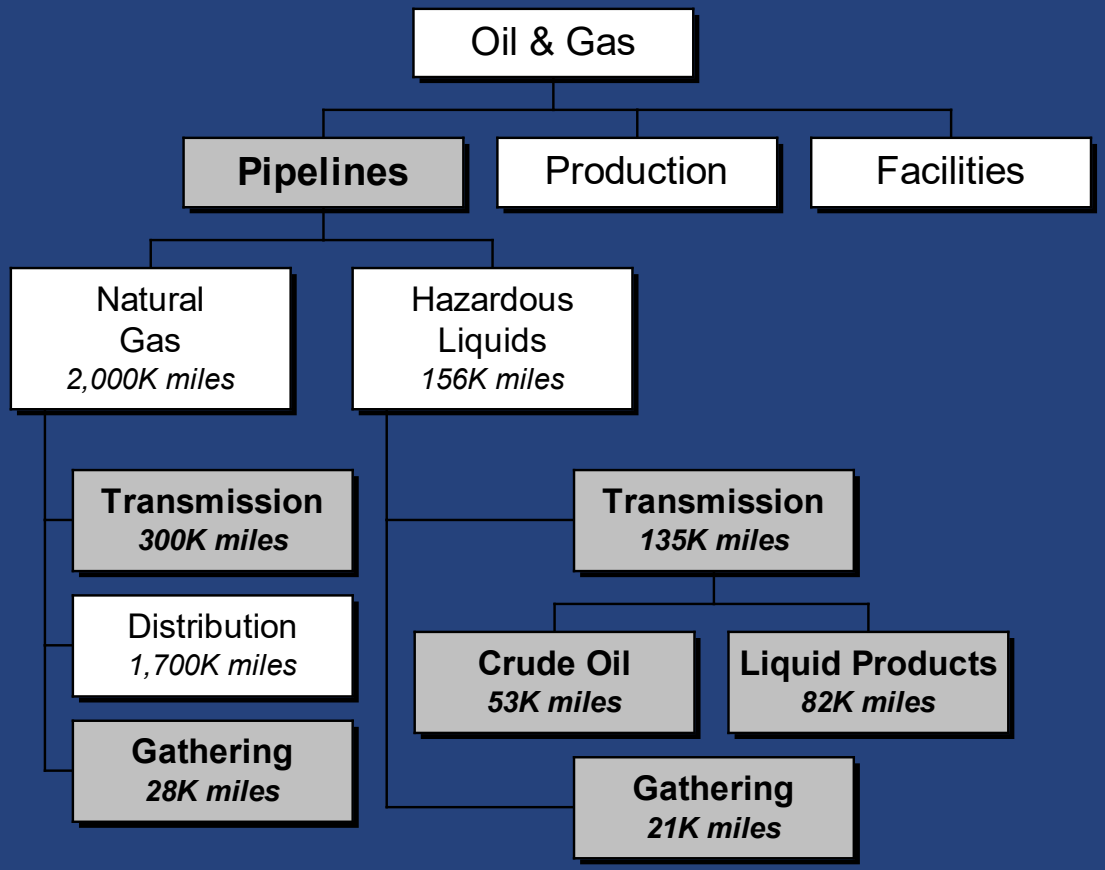
$276 Billion

The United States Cost of Corrosion Study

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



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

	Low Estimate	High Estimate	Average	
	($ x M)	($ x M)	($ x M)	%
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

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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

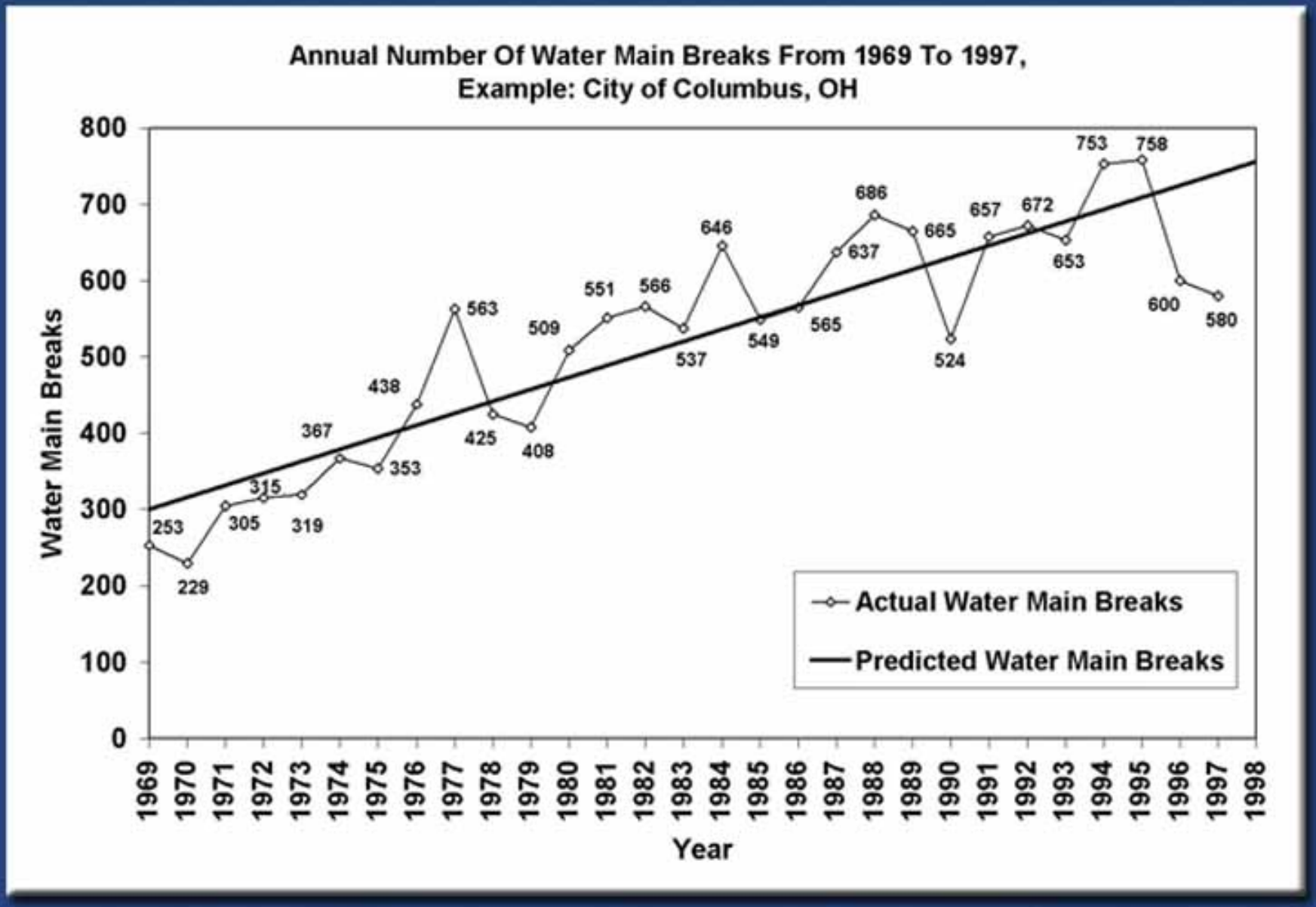
- **System Size**
  - 550 liters of water consumption per person per day
  - 56.7 Billion m^3 / year in the U.S.
  - 1.4 Million km of municipal water pumping

- 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
Water Main Breaks
Year
800
700
600
500
400
300
200
100
0
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
253
229
305
315
319
367
353
438
563
425
408
509
551
566
537
646
549
565
637
686
665
524
657
672
653
753
758
600
580
Actual Water Main Breaks
Predicted Water Main Breaks

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

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Background

- Significant available onshore oil & gas reserved 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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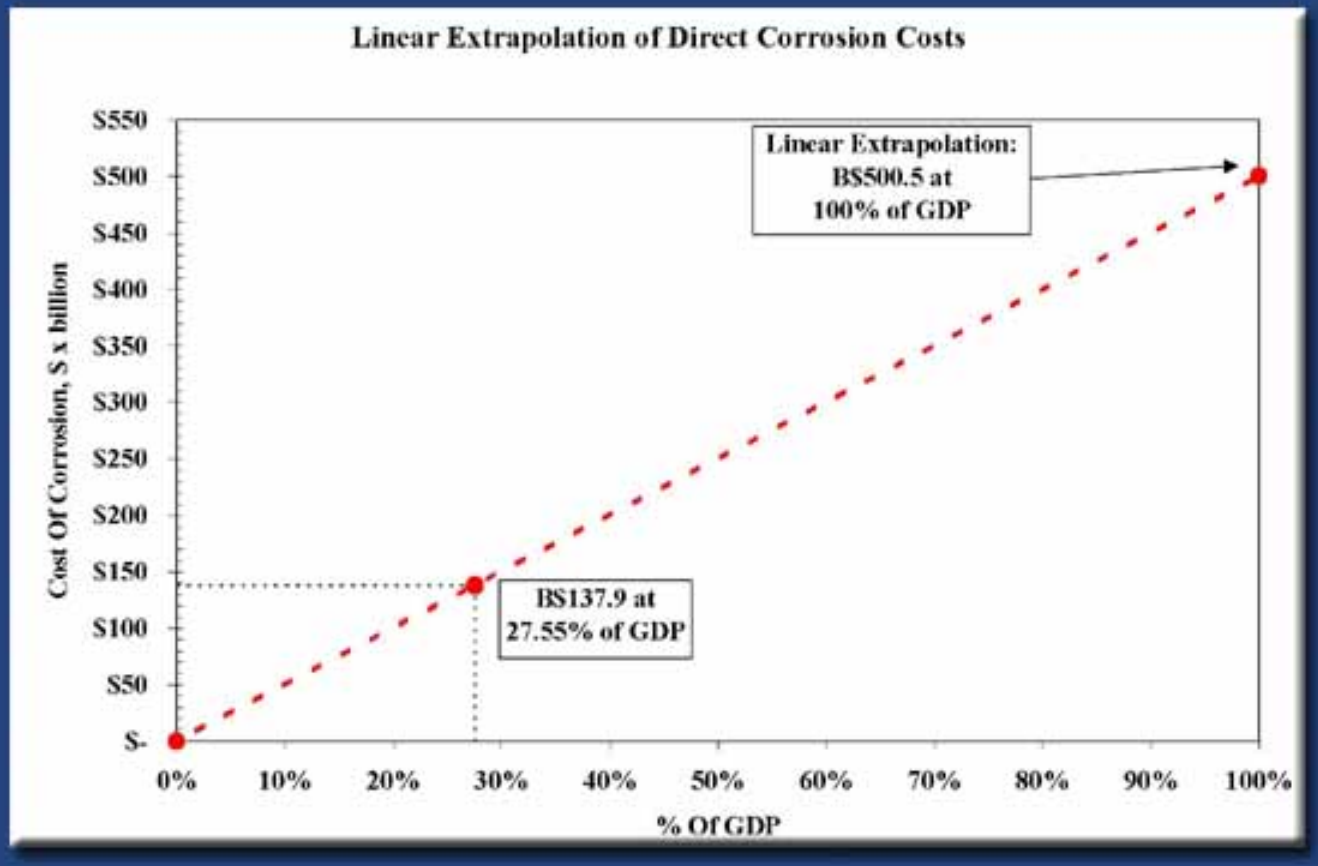
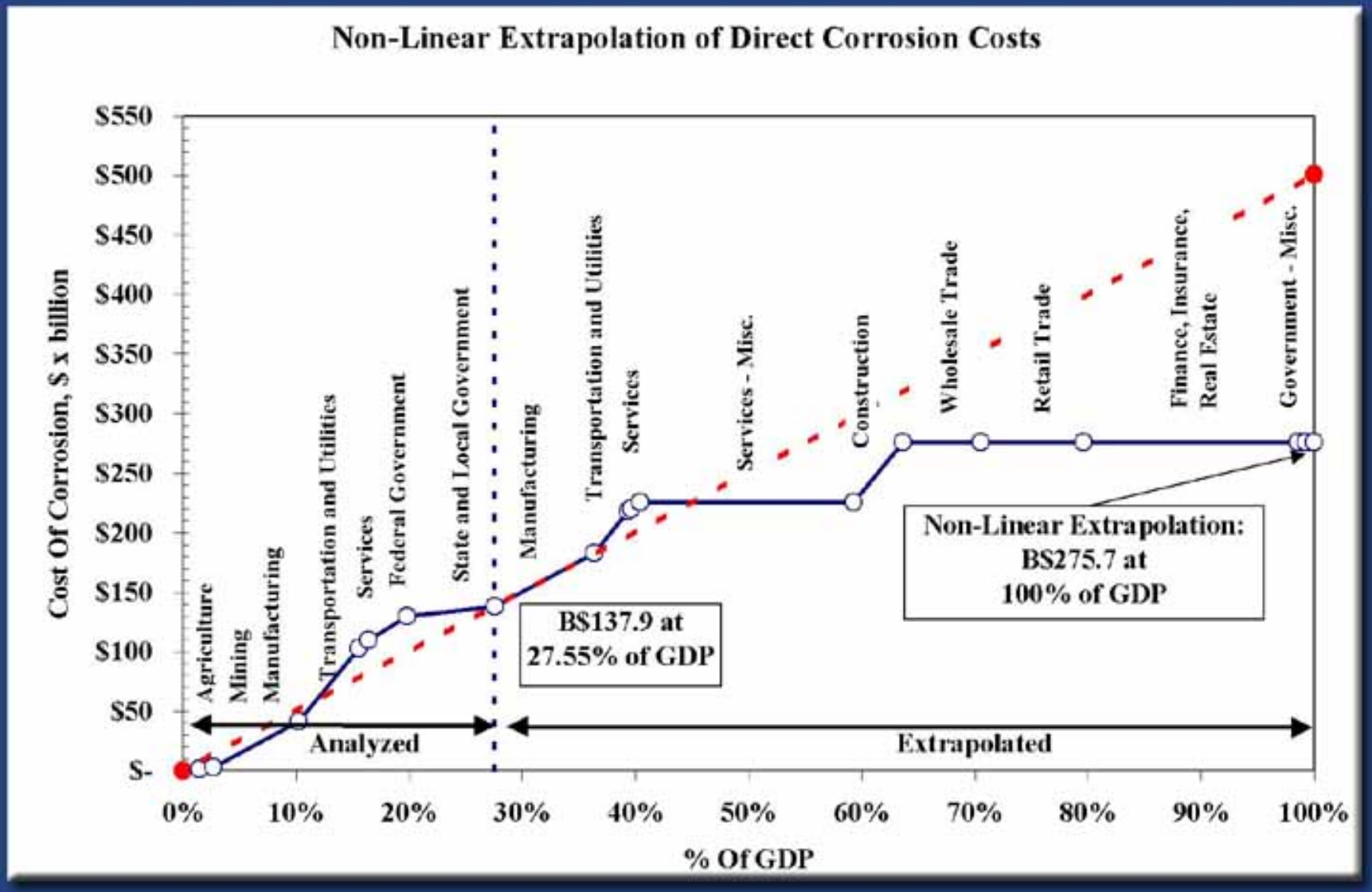
The United States Cost of Corrosion Study


Linear Extrapolation of Direct Corrosion Costs
Cost Of Corrosion, $ x billion
$550
$500
$450
$400
$350
$300
$250
$200
$150
$100
$50
$-
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
% Of GDP
Linear Extrapolation:
B$500.5 at
100% of GDP
B$137.9 at
27.55% of GDP

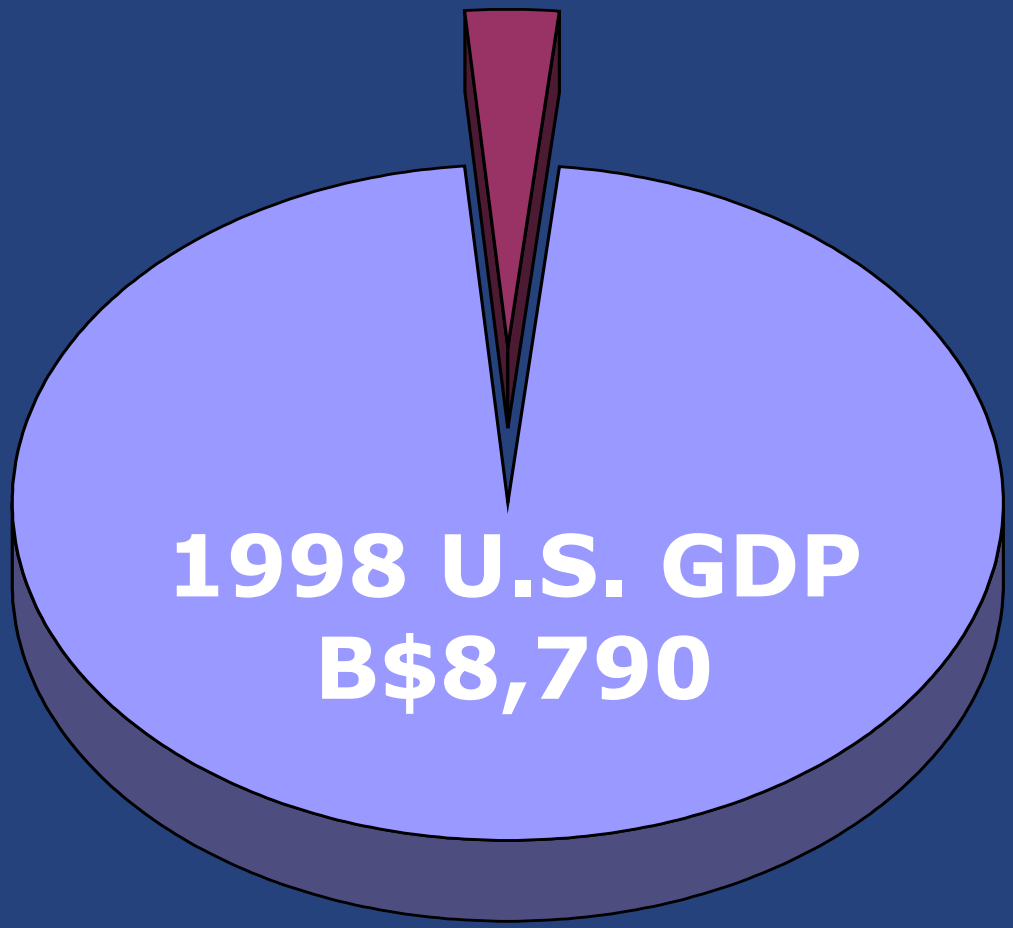

Non-Linear Extrapolation of Direct Corrosion Costs
Cost Of Corrosion, $ x billion
$550
$500
$450
$400
$350
$300
$250
$200
$150
$100
$50
$-
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
% Of GDP
Agriculture
Mining
Manufacturing
Transportation and Utilities
Services
Federal Government
State and Local Government
Manufacturing
Transportation and Utilities
Services
Services - Misc.
Construction
Wholesale Trade
Retail Trade
Finance, Insurance, Real Estate
Government - Misc.
Analyzed
Extrapolated
B$137.9 at
27.55% of GDP
Non-Linear Extrapolation:
BS275.7 at
100% of GDP

Total Cost of Corrosion

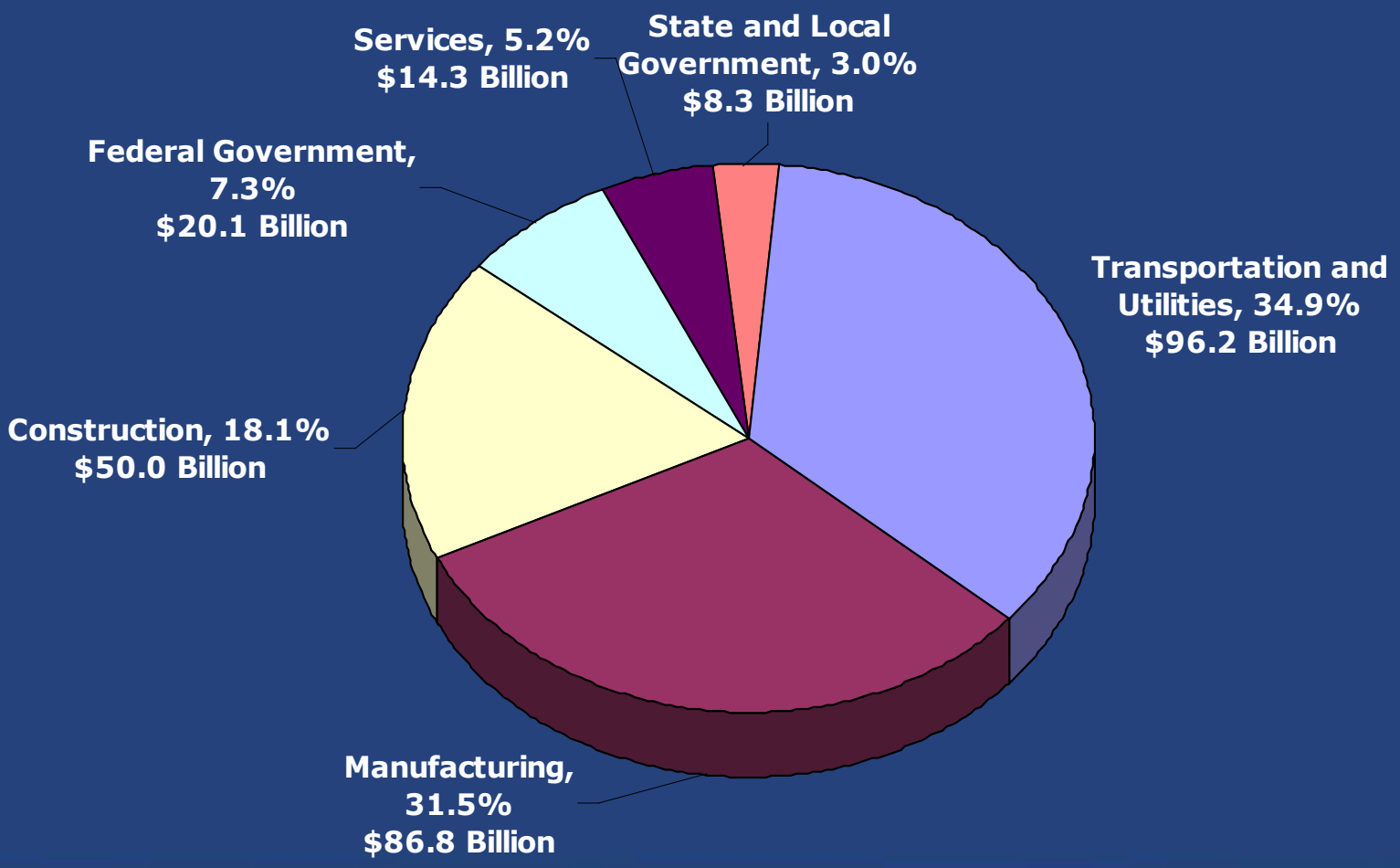
- Estimated Cost B$138
- Extrapolated Cost B$276
- Actual Cost >B$550

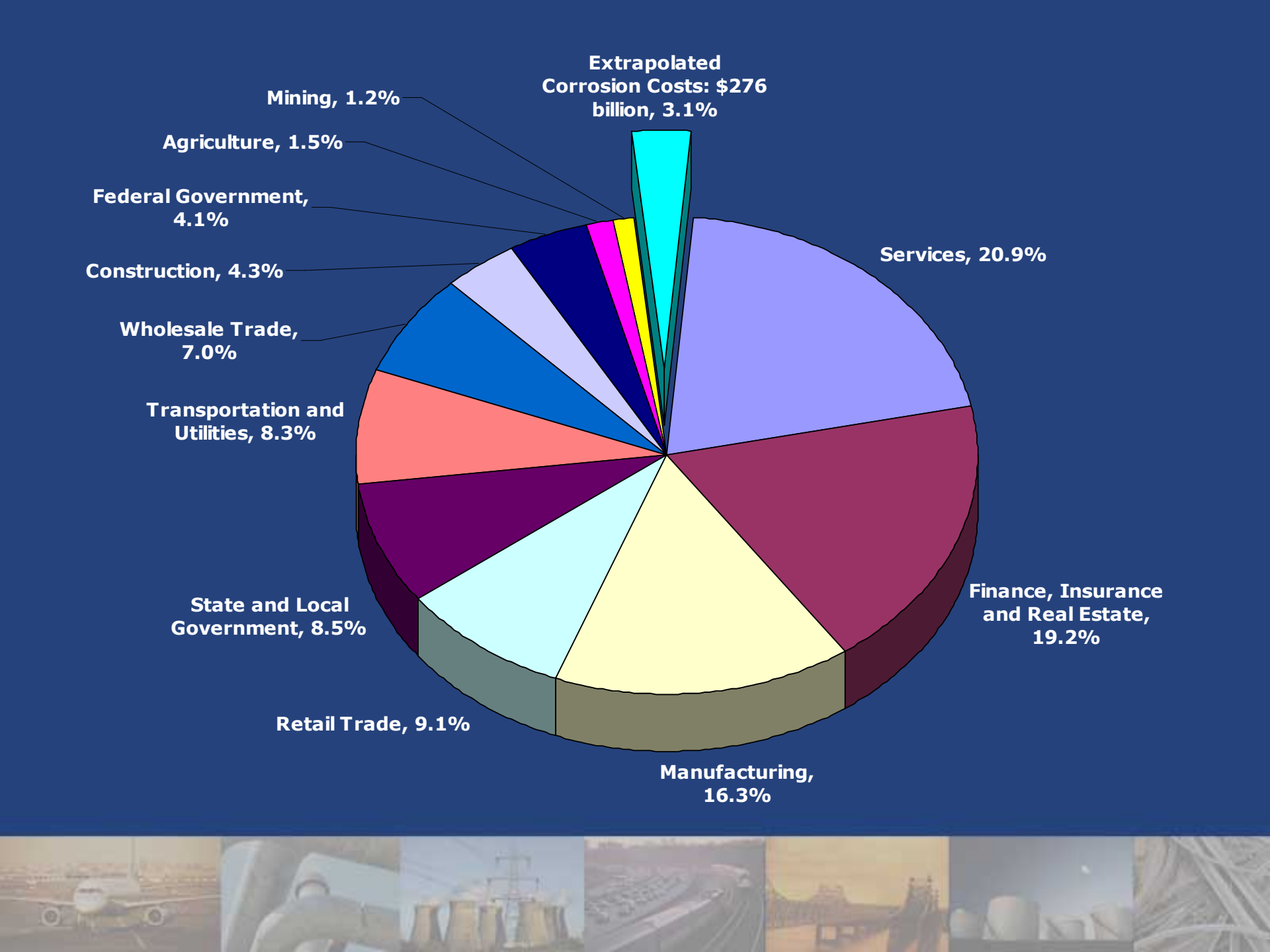
- Bridges >5 times
- Electric Utilities >3 times

Total Direct Cost of Corrosion in the U.S.
B$276 / year = 3.1% of GDP



Extrapolated Corrosion Costs: $276 billion, 3.1% of GDP




Extrapolated Corrosion Costs: $276 billion, 3.1%
Mining, 1.2%
Agriculture, 1.5%
Federal Government, 4.1%
Construction, 4.3%
Wholesale Trade, 7.0%
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%
Services, 20.9%

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:
    - Federal Highway Administration
    - Y. Paul Virmani (202) 493-3052

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

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