



# What We've Learned About Biofilms...

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**CHEM-AQUA**

**UAB** THE UNIVERSITY OF  
ALABAMA AT BIRMINGHAM

# **Biofilms: The Root Cause of Many Costly Problems**

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**Biofilm related problems associated with engineered water systems cost billions annually e.g.**

- Corrosion
- Fouled heat exchangers
- Clogged piping and membranes
- Equipment maintenance and replacement
- Unexpected equipment failure
- Disease and infection

# **Biofilms and Biological Control**

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**As an industry, the next decade will be about improving biological control**

**Our collaboration with UAB and others has helped gain a better understanding of the nature of biofilms**

**This should lead to improvements in WT programs to provide enhanced protection for and better performance from your key utility systems**

# The University of Alabama at Birmingham





# The University of Alabama at Birmingham

- **UAB is a research university and academic health center**
- **21,245 employees (Alabama's largest employer)**
- **\$7.15 billion annual economic impact**
- **19,535 students**
- **185 owned buildings and 50 leased buildings**
- **17 million GSF of space**



# Three Central Plants

Central Utilities Plant #1



14,000 Tons - 6 Machines

Central Utilities Plant #3



16,000 Tons - 7 Machines

Central Utilities Plant #5



8,000 Tons - 2 Machines (9,000 Tons future)

38,000 Tons Total Capacity

# Physical Plant Operations

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- 15 centrifugal chillers (2,000 to 4,000 tons)
- 19 cooling towers
- 24/7/365 Operations
- 42°F supply
- 54°F return
- 2 million gallon underground chilled water loop
- 1 million gallons/day summer peak tower makeup
- PLC controlled to maximize operation and efficiency

# UAB Physical Plant

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- **52 of our most critical buildings served**
  - **Approximately 8 million ft<sup>2</sup>**
- **60% of the buildings are hospital operations**
- **40% are research labs and comfort cooling**
- **Every building is connected to the distribution system with a flow meter measuring CHW flow**
  - **Supply and return temperatures are also recorded**
  - **Buildings are charged monthly for MMBTU usage**
  - **1.235 million MMBTU provided FY1617**



# **Why is UAB Concerned about Biofilms?**

- **System Longevity**
  - Millions of dollars of equipment
- **Energy Efficiency**
  - Even a 1% energy savings is huge
- **Control of Water Borne Pathogens (WBP's)**
  - Safety of our students, staff and visitors is our #1 concern

# What are Biofilms?

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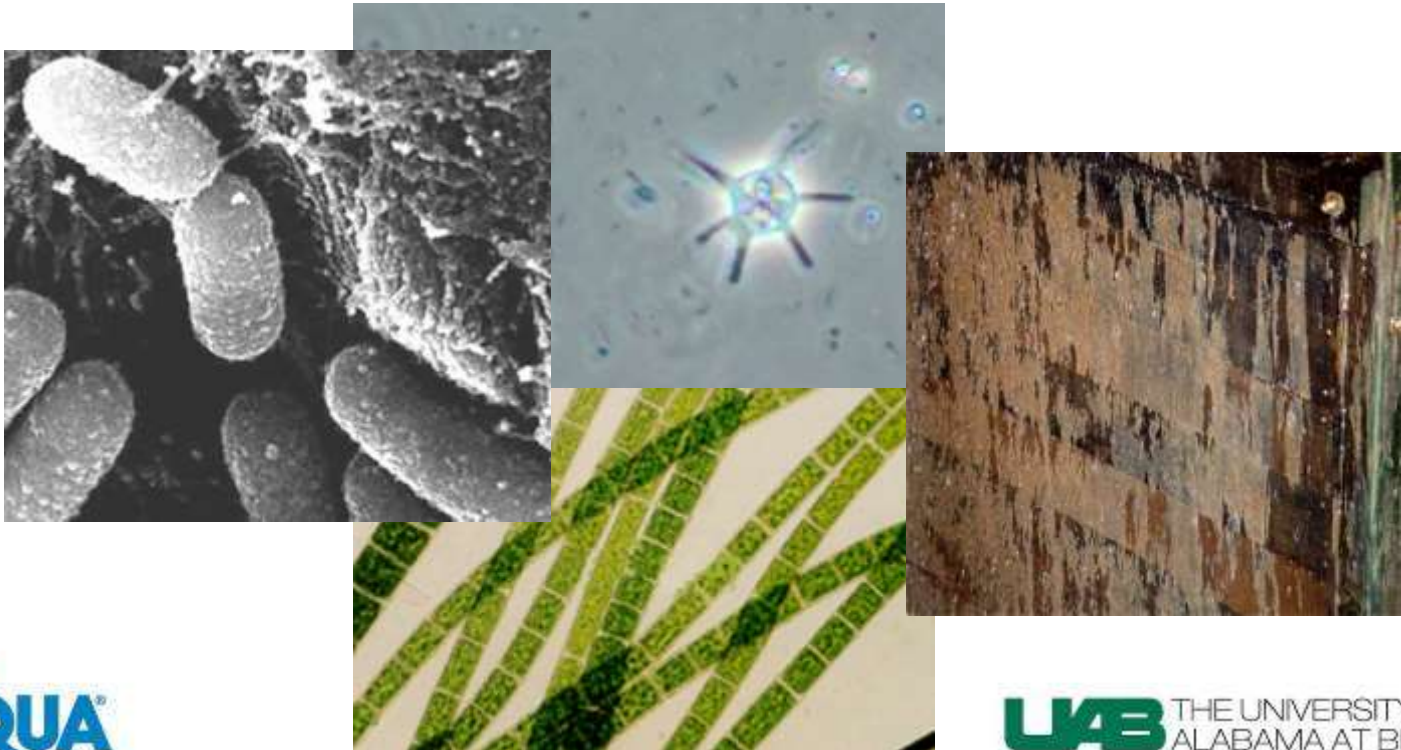
- **Complex communities of surface attached microorganisms held together by gelatinous microbial secretion called Extracellular Polymeric Substance (EPS)**



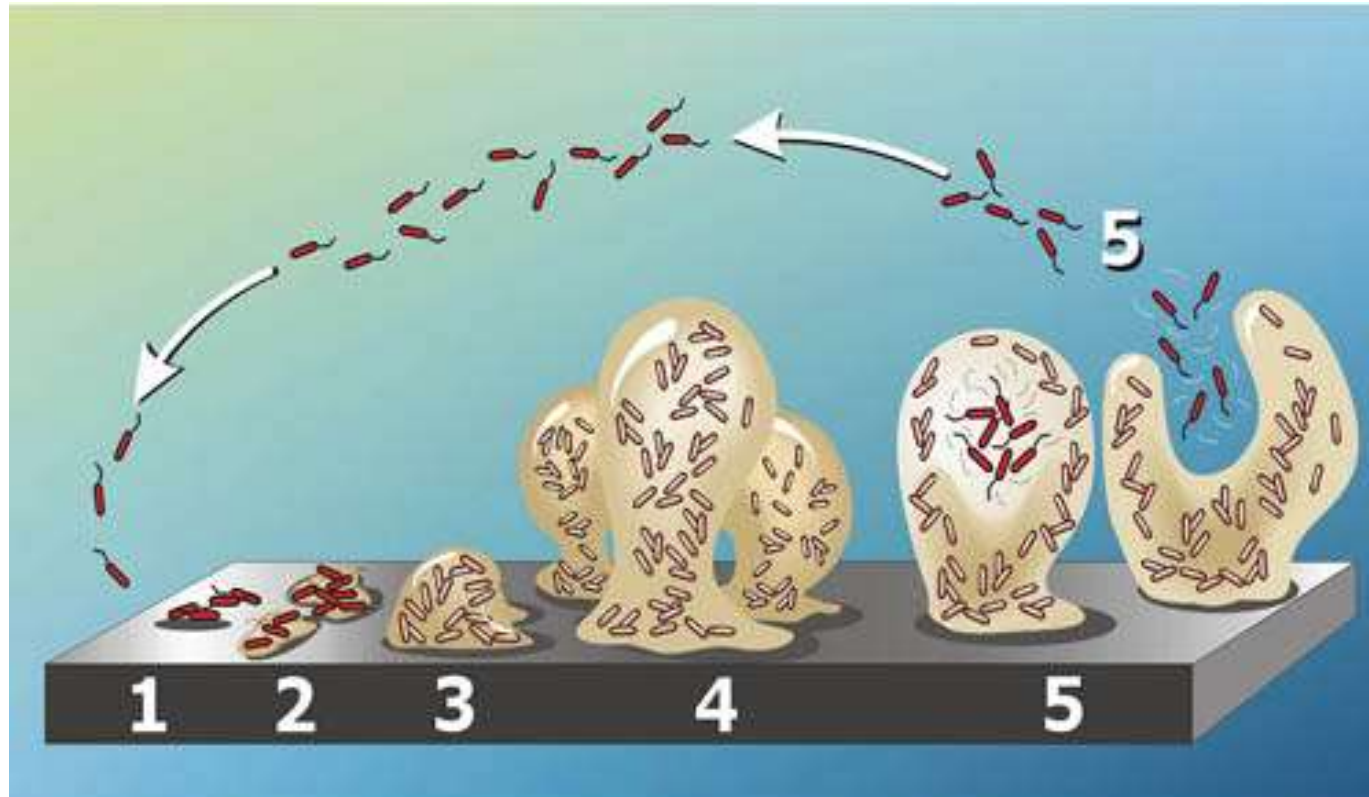
# Biofilms: Diverse Population of Organisms

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- Biofilms are composed of many different microorganisms including bacteria, algae, fungus, and protozoa
- Different biofilms form under different environmental conditions

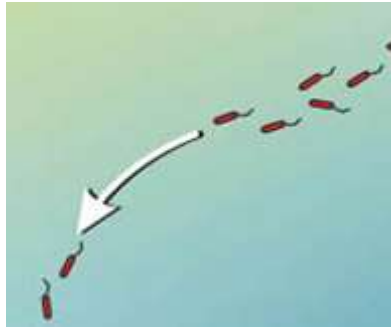


# Biofilms are Sturdy and Fast Forming





# Steps in Biofilm Formation



**Planktonic  
(Free swimming)  
bacteria in  
bulk water**



**Reversible  
Adsorption  
of Bacteria  
(Seconds)**



**Irreversible  
Attachment  
of Bacteria  
(Seconds -  
minutes)**



**Growth and  
Division  
of Bacteria  
(Hrs - days)**



**EPS Production  
& Biofilm Formation  
(Hrs- days)**



# Steps in Biofilm Formation (Cont'd)

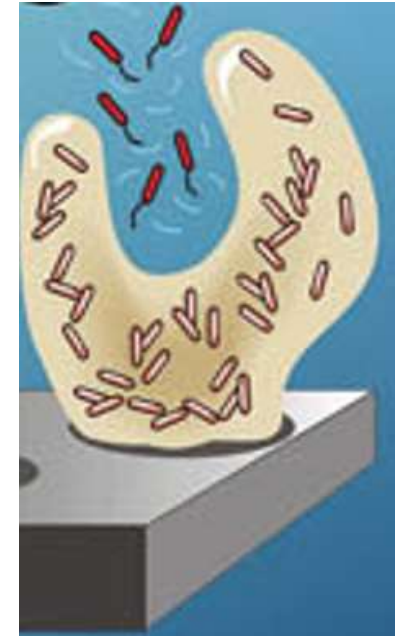
Back to square 1...



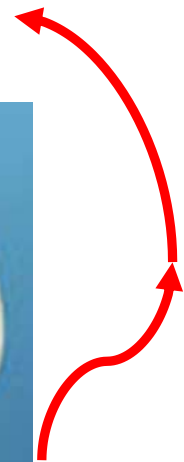
**EPS Production  
& Biofilm Formation  
(Hrs - days)**



**Ingestion &  
Attachment of Other  
Organisms to Biofilm  
(Days - months)**

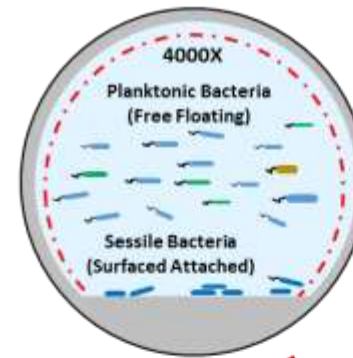
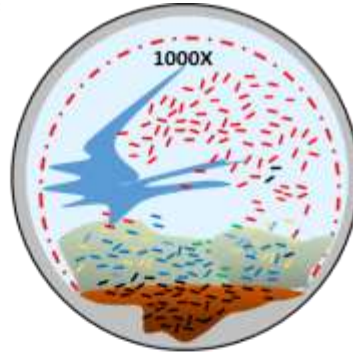


**Propagation  
& re-inoculation  
of bulk water  
(On-going)**

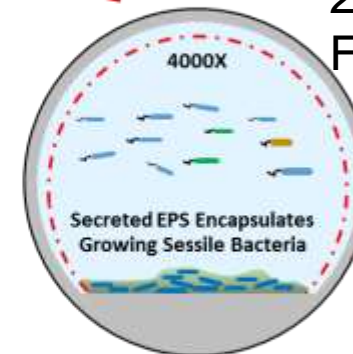


# How do Biofilms Relate to Legionella?

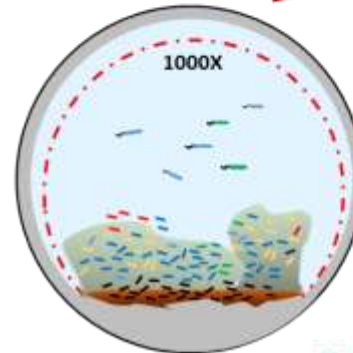
6. Amoeba  
Ruptures Releasing  
Legionella



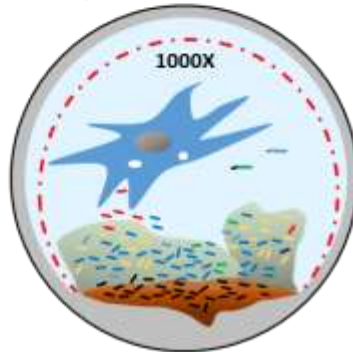
1. Surface  
Attachment



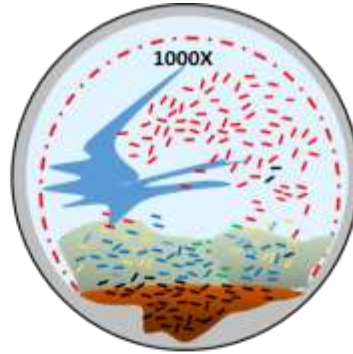
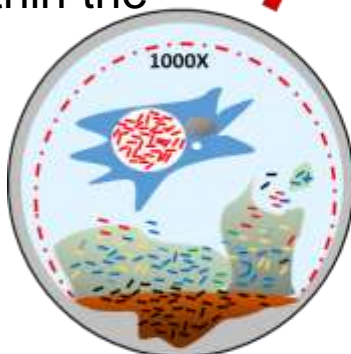
2. Biofilm  
Formation



3. Legionella  
Multiply in Biofilm



4. Amoeba ingest  
Legionella



# Biofilms Are Resistant to Biocides

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Bacteria can become resistant to biocides, especially oxidizers, which are indiscriminate. Oxidizers are easily exhausted before they can penetrate the biofilm.

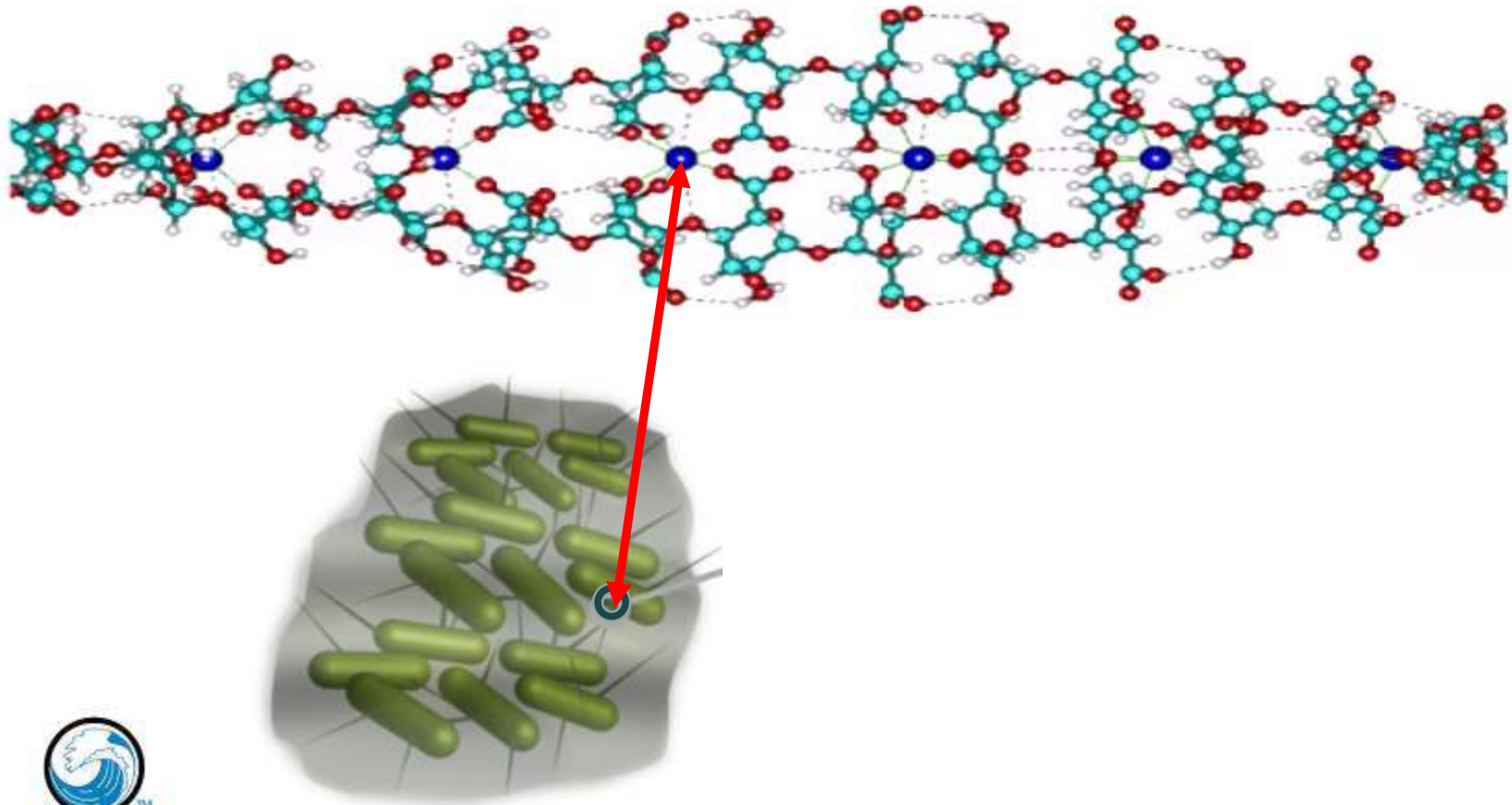


Biofilm subjected to 15 ppm free chlorine (confocal microscopy with viable bacteria dyed green)

Video courtesy of Montana State  
Center for Biofilm Engineering

# Biofilms are Tough

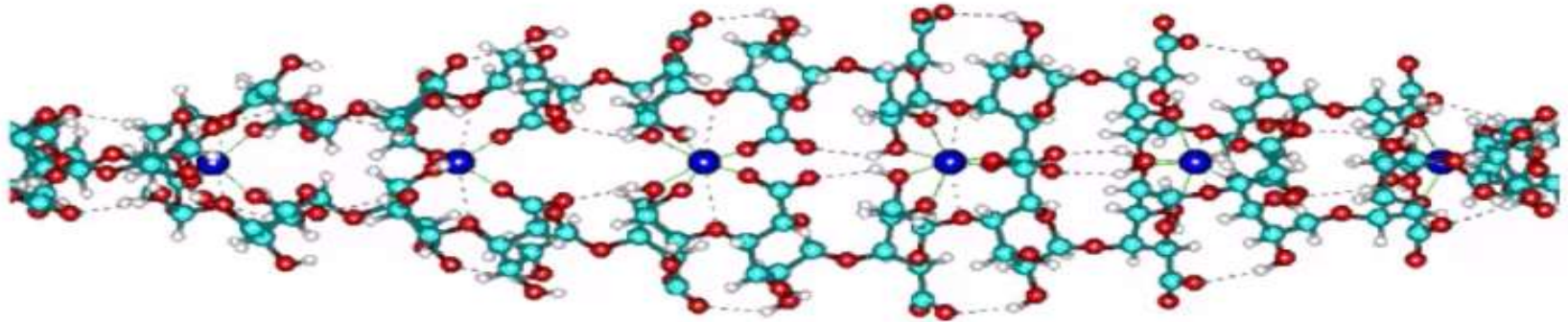
The molecules that form the biofilm are bound together with a locking mechanism known as the CALCIUM BRIDGE. The calcium bridge cross links the molecules to form a protective, chemically resistant matrix...





# Biofilms are Tough: Attack the Calcium Bridge

The molecules that form the biofilm are bound together with a locking mechanism known as the CALCIUM BRIDGE. The calcium bridge cross links the molecules to form a protective, chemically resistant matrix...

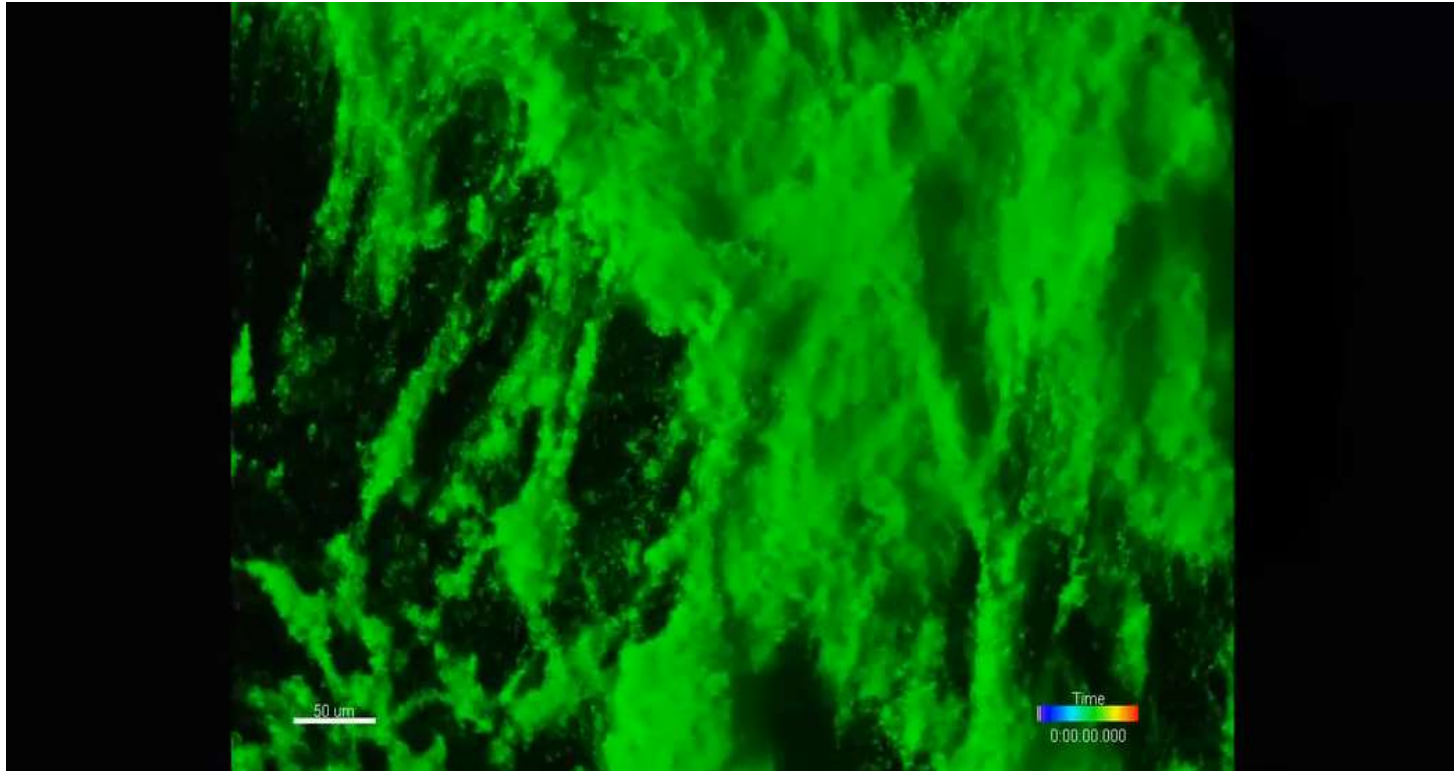




# Understanding the Challenge....

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## Insight from Montana State Center for Biofilm Engineering



# Biofilms are Smart

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- **Quorum Sensing** - Cell to cell signaling to adapt to changes in environment. Can trigger persister mechanism in the presence of biocide.
- **Persister Mechanisms** – Cells develop that essentially hibernate in the presence of biocide. They wake up and multiply after the biocide threat is gone.
- **Gene transfer** – movement of genes between organisms to make them stronger and more resistant.

Unless completely removed, the surviving bacteria multiply rapidly  
TO FORM A NEW, MORE RESISTANT AND IMPERVIOUS BIOFILM.  
This is called...

## The Persister Mechanism



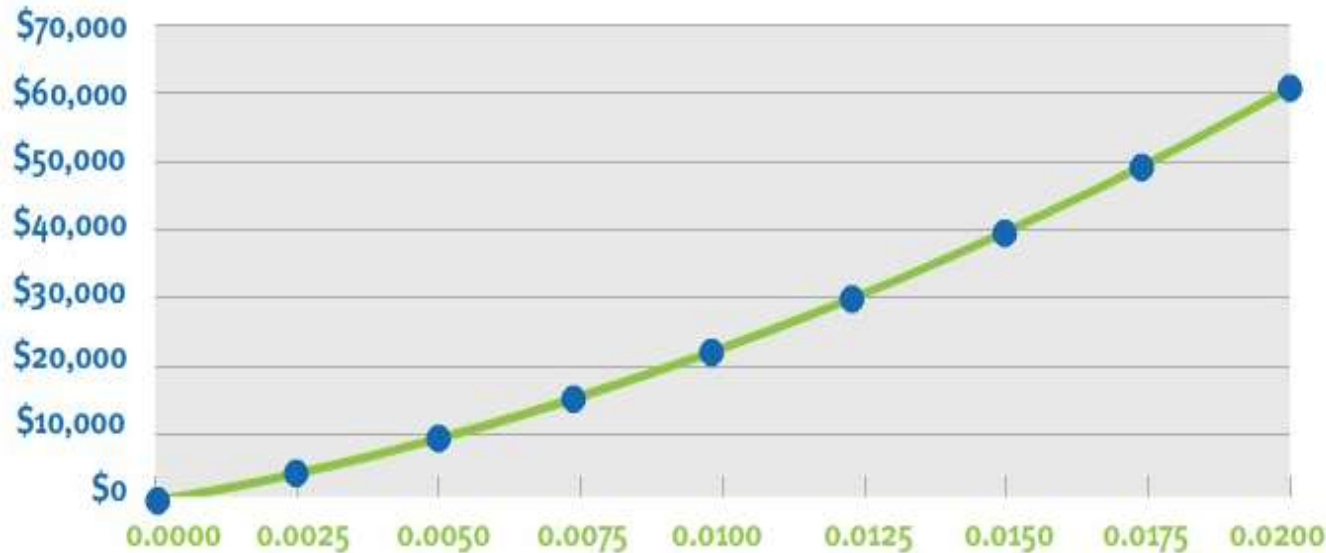
Remaining persister cells



stronger more impervious cells

# Efficient Energy Consumers

**Biofilm deposits are very insulating. They reduce heat transfer efficiency 4X more than calcium scale deposits!**



**0.005" biofilm in a 500 ton chiller operating at a 30% load increase annual electricity costs by over \$10,000**

Data from: Carrier Corporation: Handbook of Air Conditioning System Design; volume 1; McGraw Hill/ O.J. Nussbaum (author)

# Microbial Influenced Corrosion

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- Corrosive bacteria can grow to high levels within biofilms causing severe damage and failure in heat exchange equipment and system piping
- Three major types:
  - Sulfate Reducing Bacteria (SRB)
  - Iron Related Bacteria (IRB)
  - Nitrifying/Denitrifying Bacteria



# Challenges Faced by Our Industry

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- **Difficulty and expensive to measure**
  - **Current microbiological tests only measure planktonic bacteria**
    - Dip slides, Total Heterotrophic Plate Counts (THPC) etc..
  - **There is no established correlation between planktonic bacteria counts and sessile concentrations**
- **Where/how to sample and analyze**
  - **Can't open the chiller to swab the chiller barrels**
- **Stagnant conditions**
  - **Impact of seasonal operation and equipment rotation**
  - **Dead legs**



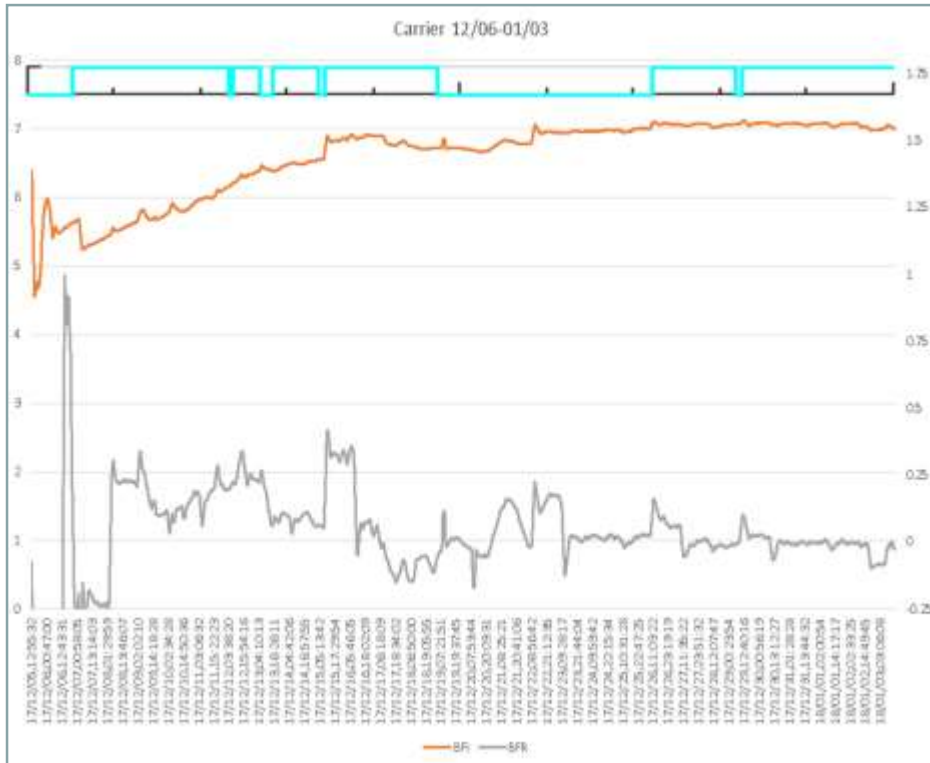
*Cooling Tower System Dead Legs Created by 1) Capped Piping Extension for System Expansion 2) Basin Equalization Line*



# Understanding the Challenges - UAB

## Carrier Tower

Intermittent System Operation



Continuous System Operation



A biomonitoring system that provides an early warning of potential biofilm problems



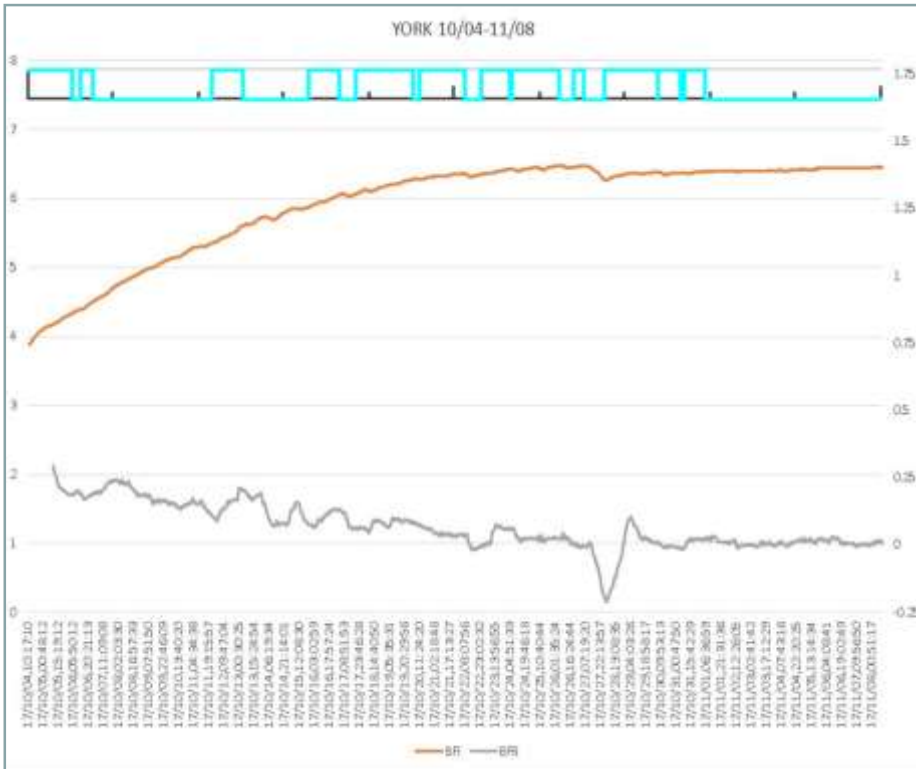
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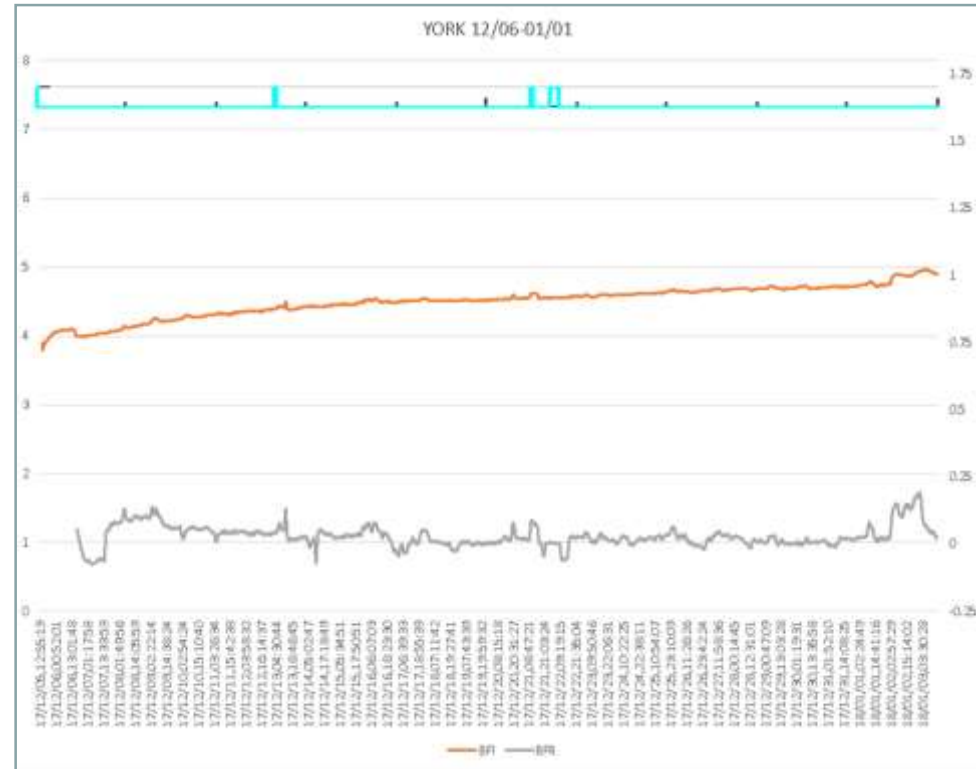
# Understanding the Challenges - UAB

## York Tower

Intermittent System Operation



Continuous System Operation



A biomonitoring system that provides an early warning of potential biofilm problems



# Insight from UAB

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- **Real time biofilm monitoring gives insight on the potential for biofilm formation based on system operations**
- **Preventative measures for offline systems decrease the potential for biofouling problems**

# **Analytical Tools - New Technology**

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- **Culturing with VBNC in consideration**
  - “The Great Plate Count Anomaly”
- **Carbohydrate Analysis in measuring EPS**
  - The bulk material of EPS
- **DNA Analysis**
  - Distinguishing between bacteria cells and particulate matter
- **Gene Sequencing**
  - Identifying the bacterial inhabitants

# Can we Eradicate these Hooligan Biofilms?

- **Difficult to completely eradicate**
- **Biomonitoring can help stay on top (field and lab methods)**
- **Real-time monitoring can identify potential risk for biofilm formation**
- **Combined with appropriate treatment**
  - **Must attack the calcium bridge**





# Conclusions -

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## Biofilms are Complex and Pervasive

- **We are learning why they are hard to control**
  - Calcium bridge
  - Persister mechanism
- **New technologies are emerging**
- **Collaboratively, we are learning more every day on improving system performance**
- **The more we learn, the better we are able to address related pathogens found in biofilms**

# What Are the Next Steps...

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**With UAB and our other University partners...**

- **Better quantification**
  - Biofilm density ( $\mu\text{g}/\text{cm}^2$ )?
  - How fast?
- **More data to make better decisions**
  - Categorizing different types of biofilms
- **Better technologies for removal and prevention**
  - Specialized chemistry to attack calcium bridging

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# QUESTIONS?





