Connecting FRP Composites to ASCE's *Infrastructure Report Card* and *Future World Vision*

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FX Consulting, LLC
June 21, 2021

Composites
AN INFINITE WORLD OF POSSIBILITIES

Outline of Today's Talk

- Introduction
- Defining an FRP Composite
- Attributes & Benefits of Composites in Infrastructure Applications
- Connecting FRP Composites to ASCE's Infrastructure Report Card
- Connecting FRP Composites to ASCE's Future World Vision
- Take-Home Message & Next Steps

Learning Objectives

- Define and identify a Fiber-Reinforced Polymer (FRP) composite
- Understand the benefits that FRP composites have to offer for construction and repair of infrastructure
- Become familiar with standards, specifications and costs of FRP composites
- Learn about specific case studies which demonstrate how FRP composites are being used today to improve our nation's infrastructure
- Learn about how FRP composites can provide solutions for ASCE's vision for cities of the future

You will receive one PDH credit for listening today.

Take-Home Message

There is an extremely good fit
between FRP composites
and our nation's infrastructure needs,
today and in the future.

My Background

- PhD chemist with 40 years' experience in the specialty chemicals & materials industries

- A member of the American Composite Manufacturers Association (ACMA) and the Institute for Advanced Composites Manufacturing Innovation (IACMI)

- A member of ASCE since October 2019

Why Am I Here?

- ACMA sees a huge fit between FRP composites and our nation's Infrastructure needs
  - Infrastructure Fly-In's to Capitol Hill

- ACMA uses ASCE's Infrastructure Report Card to illustrate the fit

Aviation D+	Inland Waterways D+	Schools D+
Bridges C	Levees D	Solid Waste C+
Dams D	Ports B-	Stormwater D
Drinking Water C-	Parks D+	Transit D-
Energy C-	Rail B	Wastewater D+
Hazardous Waste D+	Roads D	Overall C-

Why Am I Here?

- I attended the ASCE annual meeting in Miami in October ‘19 and experienced the Floating Cities Virtual Reality exhibit

The Floating City debuted at the ASCE 2019 Convention in Miami. PHOTO: Jason Dixson Photography

Convention attendees had the chance to experience the Future World Vision Floating City via virtual reality. PHOTO: Jason Dixson Photography

Connecting FRP Composites to ASCE

hello

FRP Composites

Defining an FRP Composite

What is a Composite?

- **Webster Definition:**

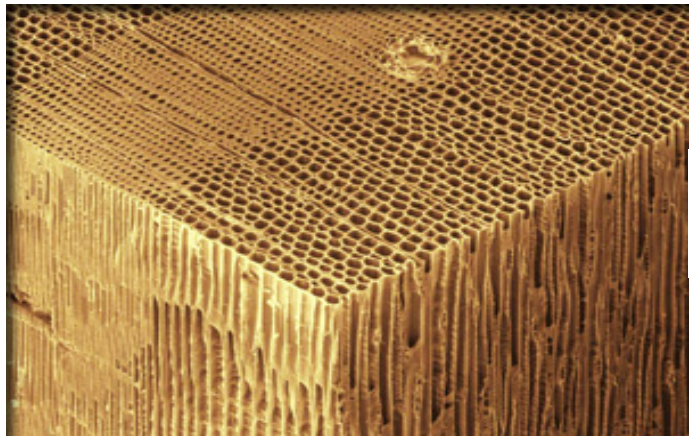
  "Something that is made up of diverse elements"

- **Wikipedia Definition:**

  "Engineered or naturally-occurring materials made from two or more constituent materials with significantly different physical or chemical properties"

Composites We Are All Familiar With….

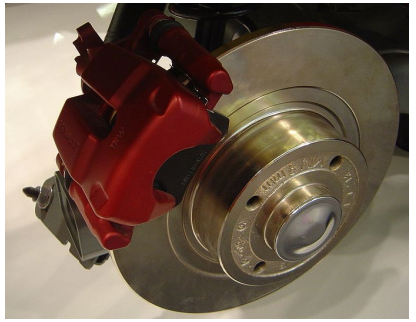
- Wood is a natural composite of cellulose fibers in a lignin matrix



- There are many man-made composites

Early civilization houses were composites of mud and straw

Modern highways are composites of concrete and steel re-bar



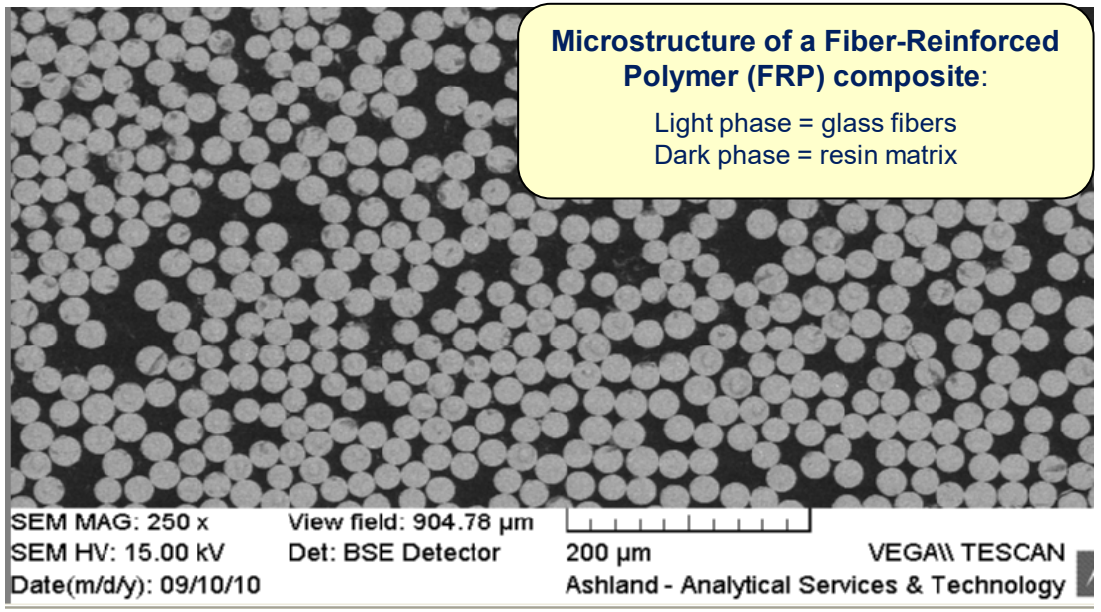
Disc brake pads are composites of hard ceramic particles embedded in soft metal

Focus for this Presentation = FRP Composites

FRP = Fiber-Reinforced Polymer Composites

A composite made from a polymer and a reinforcing fiber

- Polymer (Resin) Matrix:
  - Thermoplastic
  - Thermoset
    - Epoxy, Vinyl Ester, Unsaturated Polyester, Polyurethane …
- Reinforcing Fiber:
  - Glass (GFRP)
  - Carbon (CFRP)
  - Basalt
  - Natural



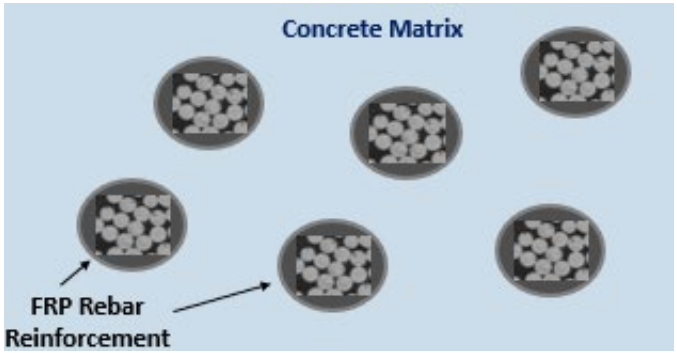
At a microscopic level, the constituent materials remain distinct within the finished structure.

FRP Rebar: A Composite Used to Make Composites

- FRP rebar can replace steel rebar in reinforced concrete
  - Used in place of epoxy-coated steel, stainless steel and galvanized steel rebar
  - Used in buildings, bridges, tunnels …….

- FRP rebar is available in a variety of shapes and sizes
  - #2 - #13
  - Relevant standard = ASTM D7957

- Concrete reinforced with FRP rebar is a composite that contains a composite!
  - Matrix = concrete
  - Reinforcement = FRP rebar



"A Composite of a Composite"

Material Substitution & Material Enhancement

- **Material Substitution:**
  - FRP composites can be used to substitute for alternative materials of construction
    - Metals
      - Steel
      - Aluminum
    - Concrete
    - Wood

More durable than wood

Lighter than metals

- **Material Enhancement:**
  - FRP composites can be used to enhance the properties of other materials
    - FRP rebar enhances the corrosion resistance and durability of reinforced concrete

More corrosion-resistant than steel-reinforced concrete

FRP Composites Find Widespread Use

- Key Markets:
  - Marine
  - Aerospace
  - Transportation
  - Equipment
  - Industrial / Corrosion
  - Building & Construction
  - Infrastructure

Marine

Aerospace

Transportation

FRP Composites Find Widespread Use

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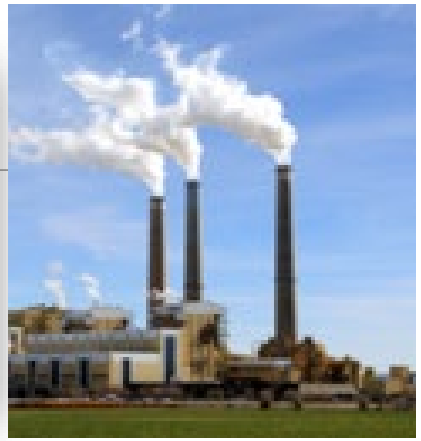
Equipment



Industrial / Corrosion

Building & Construction

Wind Energy

Infrastructure Applications of FRP Composites

Bridge Construction

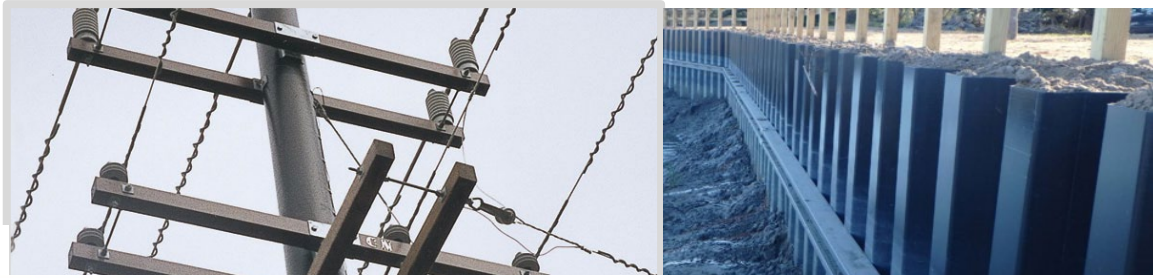
Composite rebar, decks & girders used with concrete

Water Treatment & Delivery

Durable pipes & storage vessels

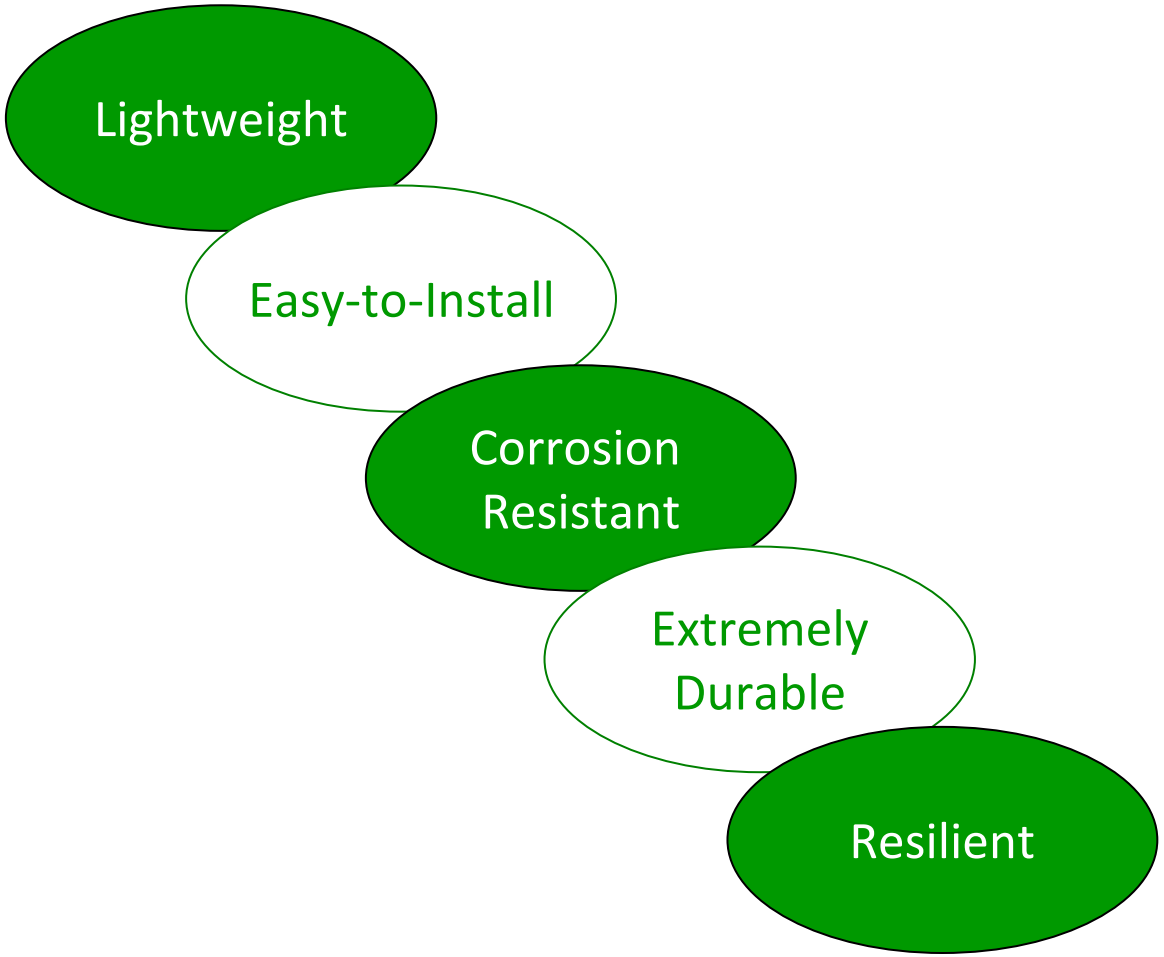
Power Poles, Piers & Seawalls

Lightweight, resilient structures

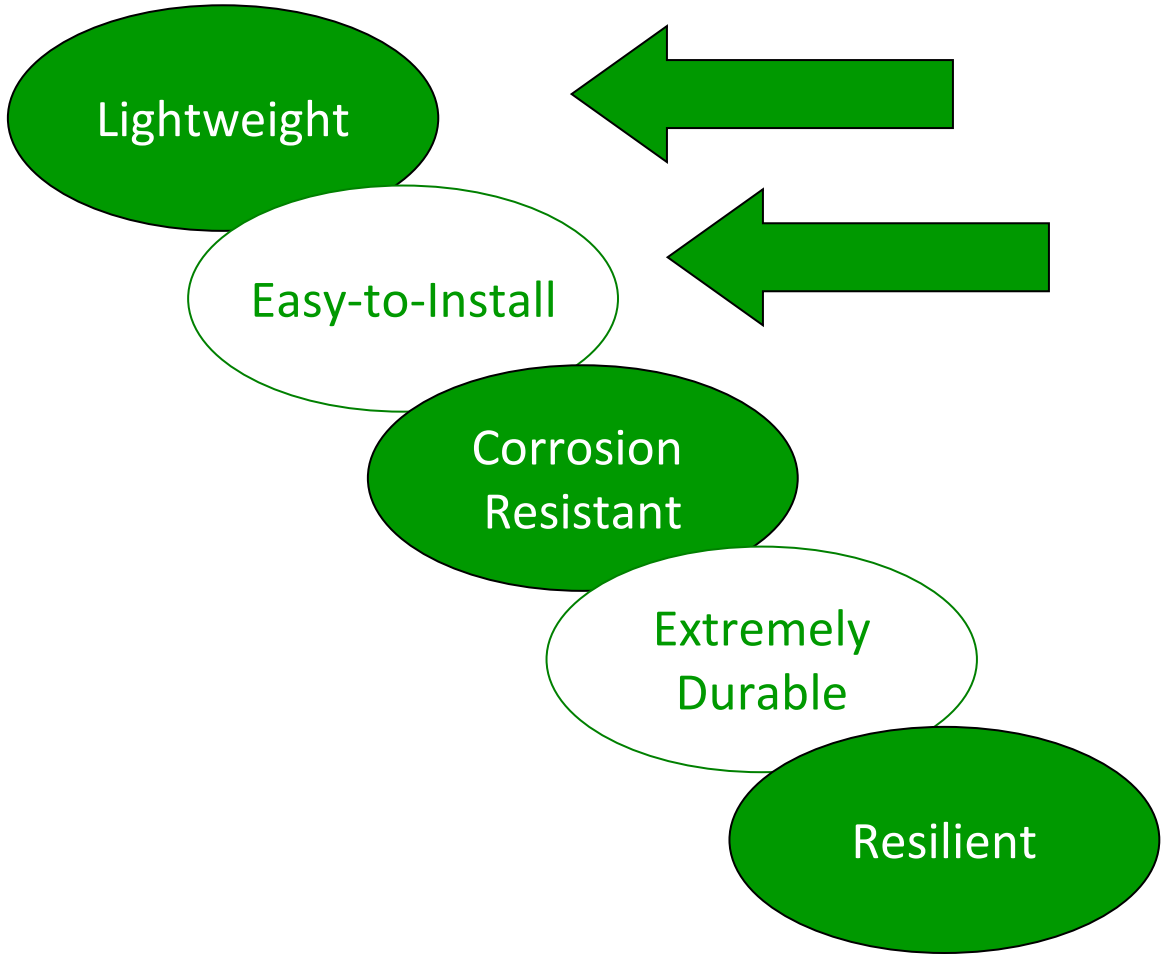


Attributes & Benefits of FRP Composites in Infrastructure & Construction Applications

Key Attributes of FRP Composites for Infrastructure Applications

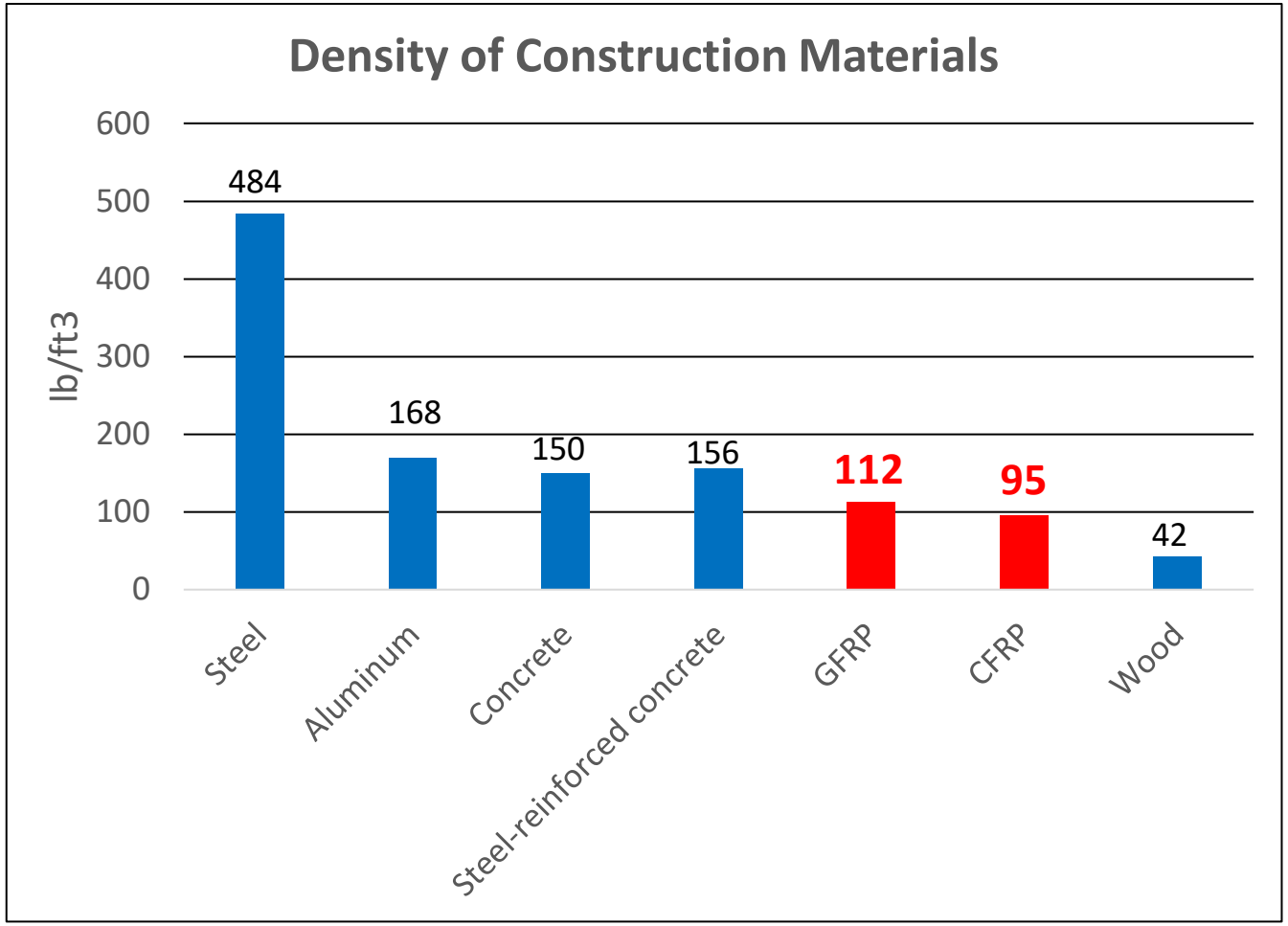


Key Attributes of FRP Composites for Infrastructure Applications



FRP Composites are Lightweight

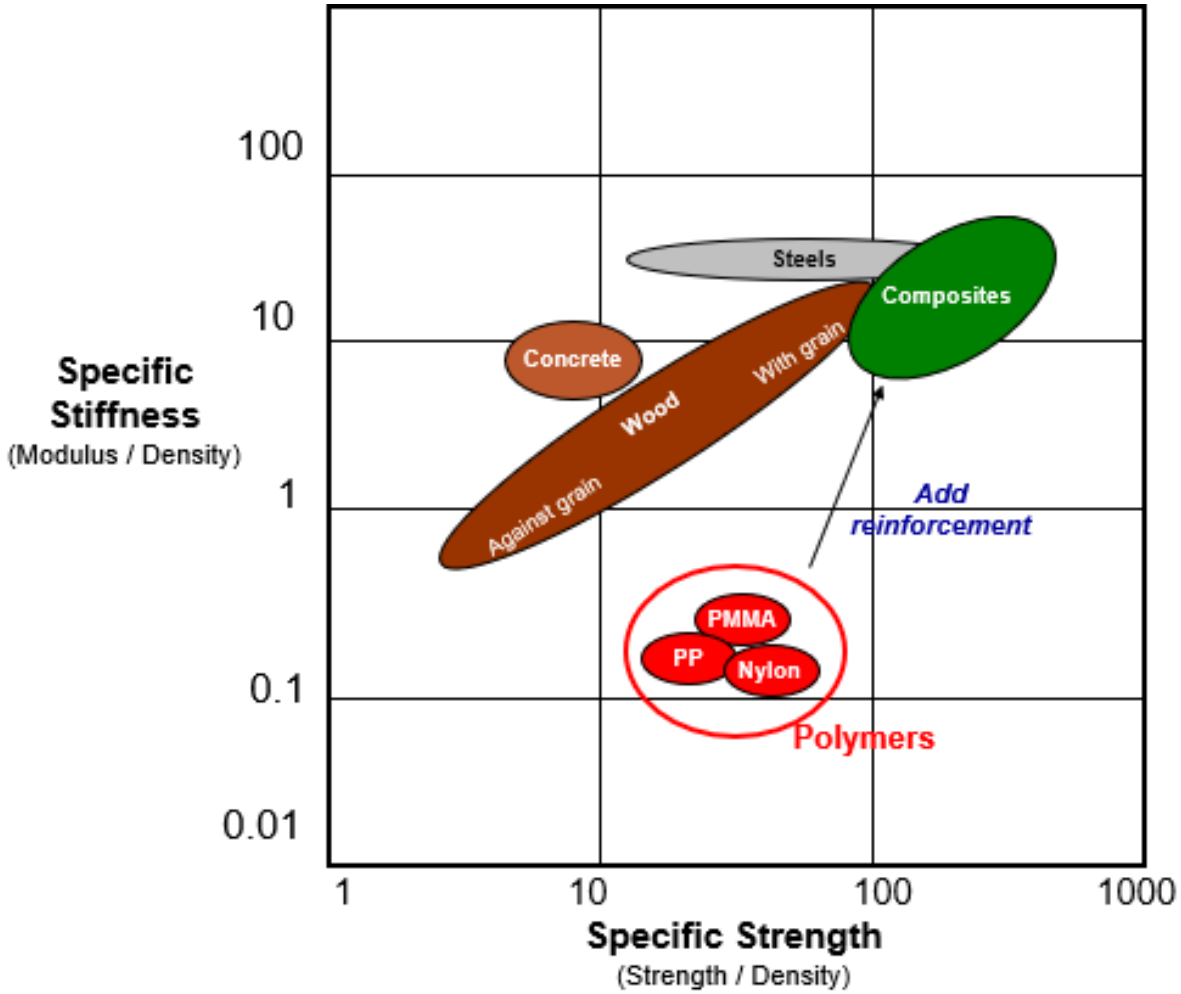
- FRP composites are lighter than steel, aluminum, concrete, and brick
  - CFRP < GFRP
- This can result in:
  - Labor savings
  - Material savings
  - Lower transportation costs
  - Less equipment during installation



Attributes	Lightweight	Easy-to-Install	Corrosion-resistant	Extremely durable	Resilient

Specific Strength & Specific Modulus

- Lightweight FRP composites have high specific strength and high specific modulus



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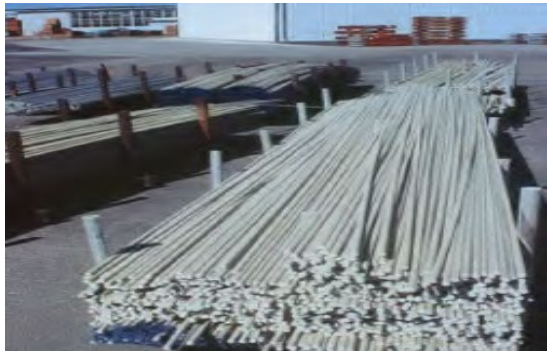
http://www-materials.eng.cam.ac.uk/mpsite/interactive_charts/spec-spec/NS6Chart.html

Lightweight FRP Rebar

Size	Diameter (in)	Linear Weight (lb/ft)		Ratio
		Steel	GFRP	GFRP/Steel
#3	0.375	0.38	0.10	0.26
#4	0.50	0.67	0.17	0.25
#5	0.625	1.04	0.29	0.28
#6	0.750	1.50	0.41	0.27
#7	0.875	2.04	0.55	0.27
#8	1.00	2.67	0.74	0.28

FRP rebar is less than 1/3rd the weight of steel rebar



Attributes	Lightweight	Easy-to-Install	Corrosion-resistant	Extremely durable	Resilient

Labor Savings

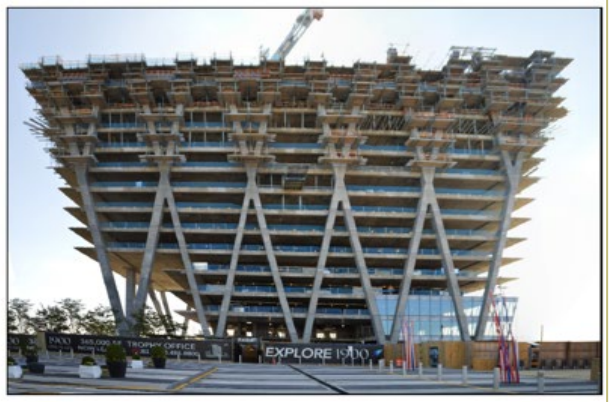
Future Impact of FRP Concrete Reinforcement on the Commercial Building Industry

Brett McMahon
CEO, Miller & Long Co., Inc.

CAMX
THE COMPOSITES AND ADVANCED MATERIALS EXPO
Convention Center | Anaheim, CA, USA

Labor Savings

- Cost and availability of labor increasingly drives overall costs
- Rodman is a hard, dirty job!
  - Increasingly harder to find people to do it.
- FRP: Potential to significantly lower reduce labor costs
  - More with less
  - More efficient



"FRP rebar is 1/3 the weight of steel rebar, which is as-valuable to the building industry as its non-corrodibility is to civil transportation owners & builders"

Attributes	Lightweight	Easy-to-Install	Corrosion-resistant	Extremely durable	Resilient

Material Savings

- The façade' of the San Francisco Museum of Modern Art uses FRP composite rain shields
  - Aesthetically-pleasing
  - Lightweight

- The use of lightweight exterior panels reduced the consumption of steel in the interior of the building by 1 million pounds

- The use of FRP reduced the construction schedule by 3 weeks


Courtesy of Kreysler & Associates

Attributes	Lightweight	Easy-to-Install	Corrosion-resistant	Extremely durable	Resilient

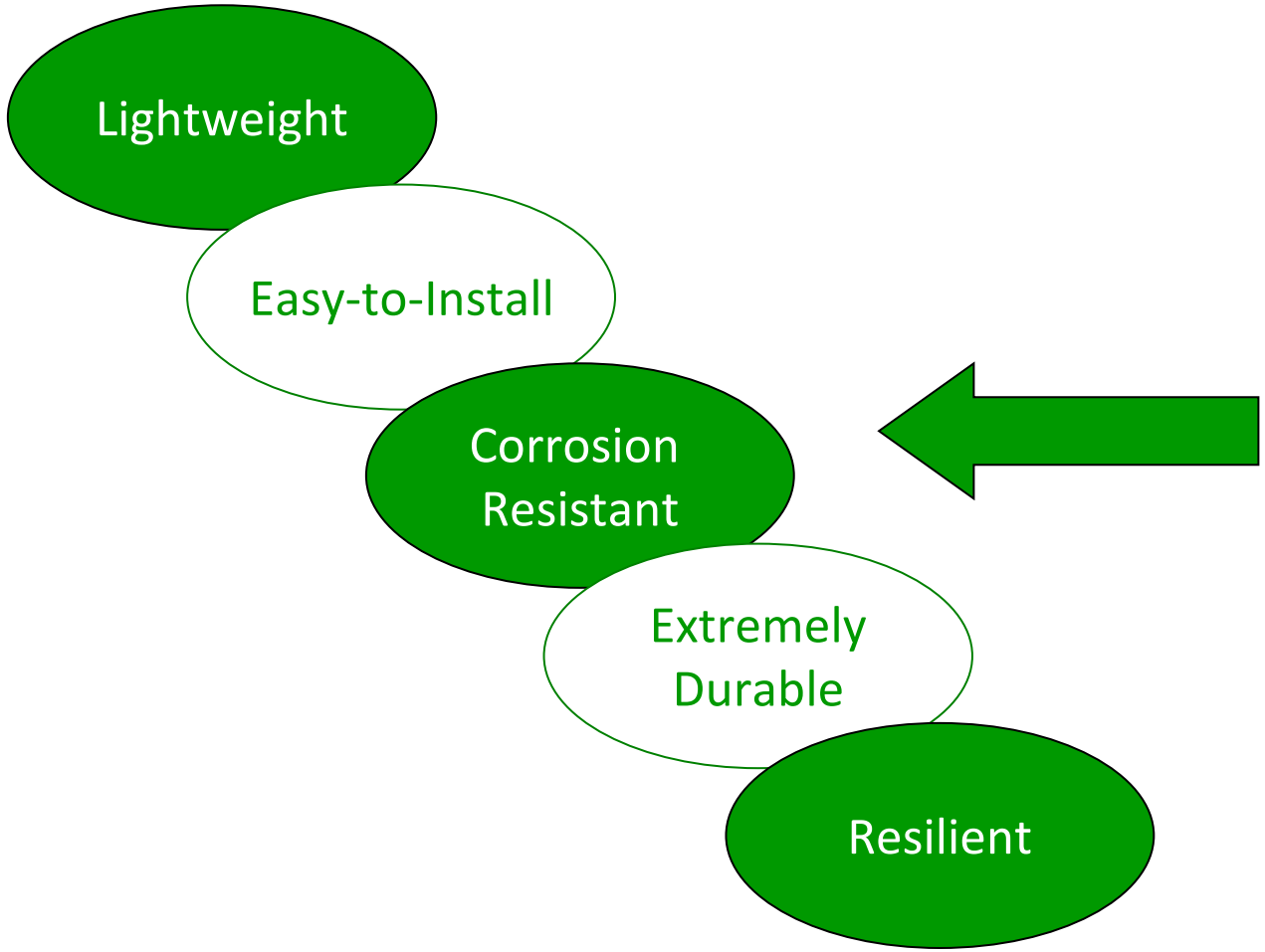
Equipment Savings

These columns were transported to the top of the Terminal Tower in a freight elevator, <u>not</u> with a crane

Courtesy of Architectural Fiberglass

Attributes	Lightweight	Easy-to-Install	Corrosion-resistant	Extremely durable	Resilient

Key Attributes of FRP Composites for Infrastructure Applications



FRP Composites are Extremely Corrosion-Resistant

- FRP composites are used in a wide variety of industrial applications where corrosion resistance is important
  - Chemical
  - Mining
  - Energy
- They find widespread use in corrosive environments
  - Pipes & tanks
  - Ductwork
  - Liners
  - Cladding for roofs & walls

Attributes	Lightweight	Easy-to-Install	Corrosion-resistant	Extremely durable	Resilient

Corrosion-Resistance of FRP Rebar

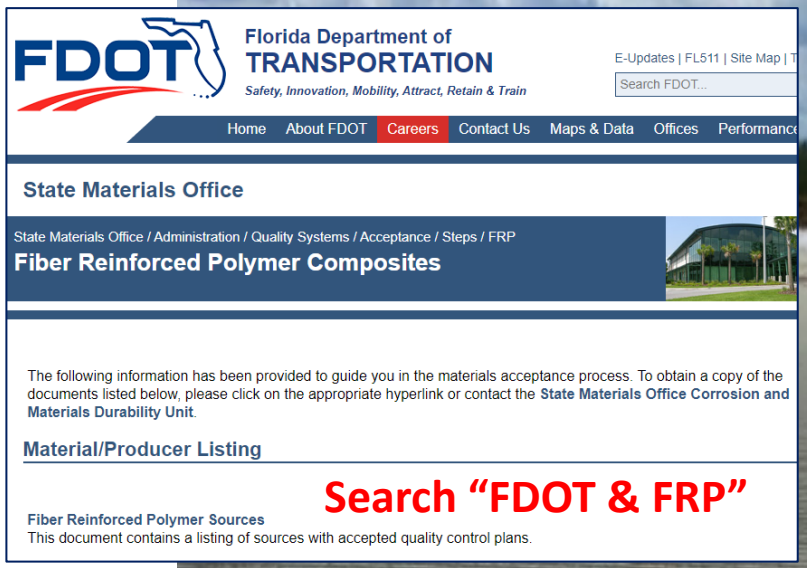
- FRP rebar is much more resistant to corrosion than steel rebar

- FRP rebar-reinforced concrete is ideal for use in chloride-containing environments
  - Seawater
  - De-icing chlorides

Attributes	Lightweight	Easy-to-Install	Corrosion-resistant	Extremely durable	Resilient

Taking Advantage of the Corrosion Resistance of FRP Composites

- The state of Florida has been a leader in the use of FRP composites and FRP rebar-reinforced concrete
  - Bridges
  - Seawalls, piles & piers
  - Marine structures
  - Traffic railings
  - Culverts
  - Sewage tunneling



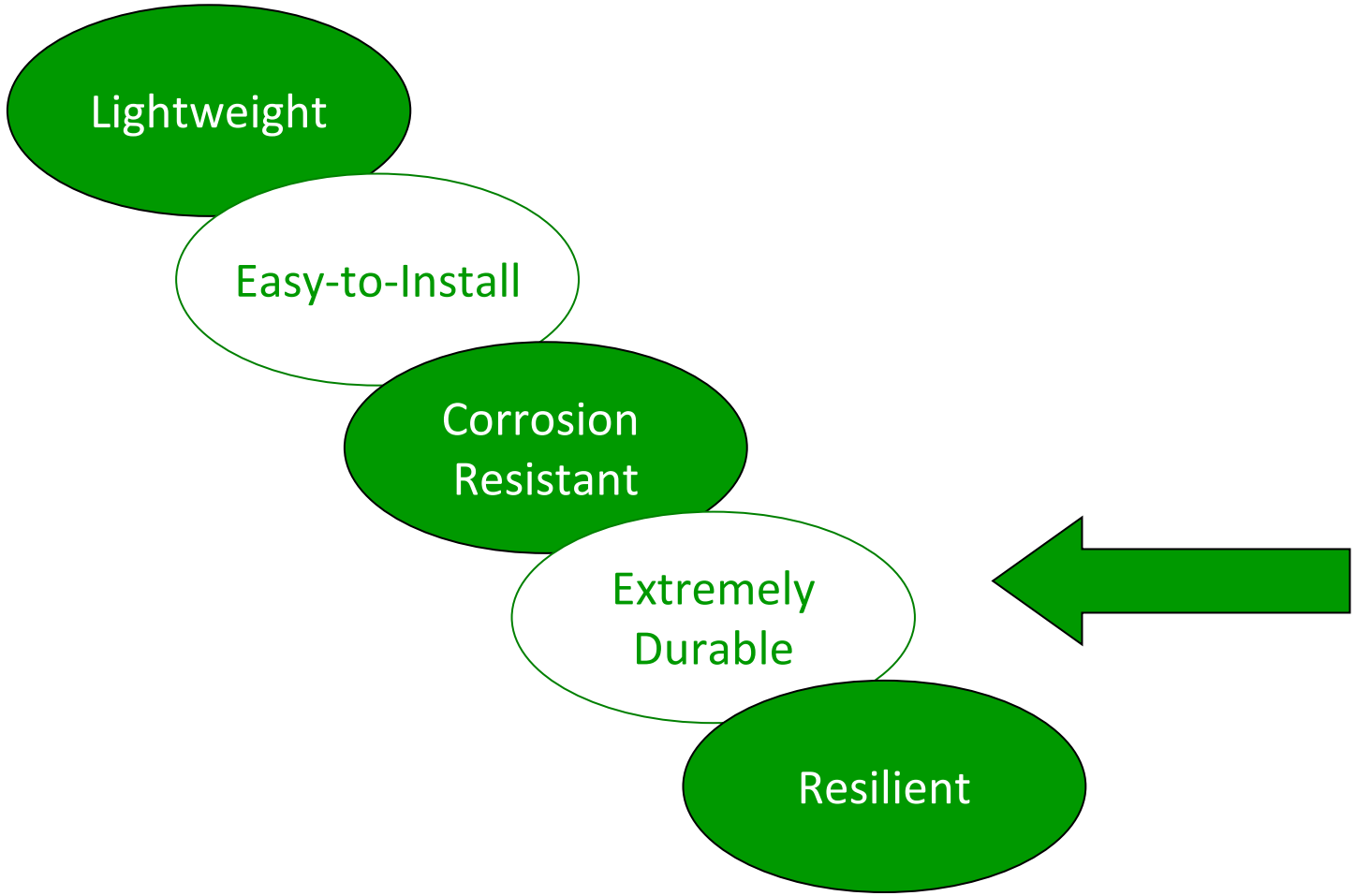
Search "FDOT & FRP"

https://www.fdot.gov/materials/quality/programs/materialsacceptance/documentation/frp.shtm

Courtesy of Owens Corning

Attributes	Lightweight	Easy-to-Install	Corrosion-resistant	Extremely durable	Resilient

Key Attributes of FRP Composites for Infrastructure Applications



FRP Composites are Extremely Durable

- FRP composites are built to last for decades

Attributes	Lightweight	Easy-to-Install	Corrosion-resistant	Extremely durable	Resilient

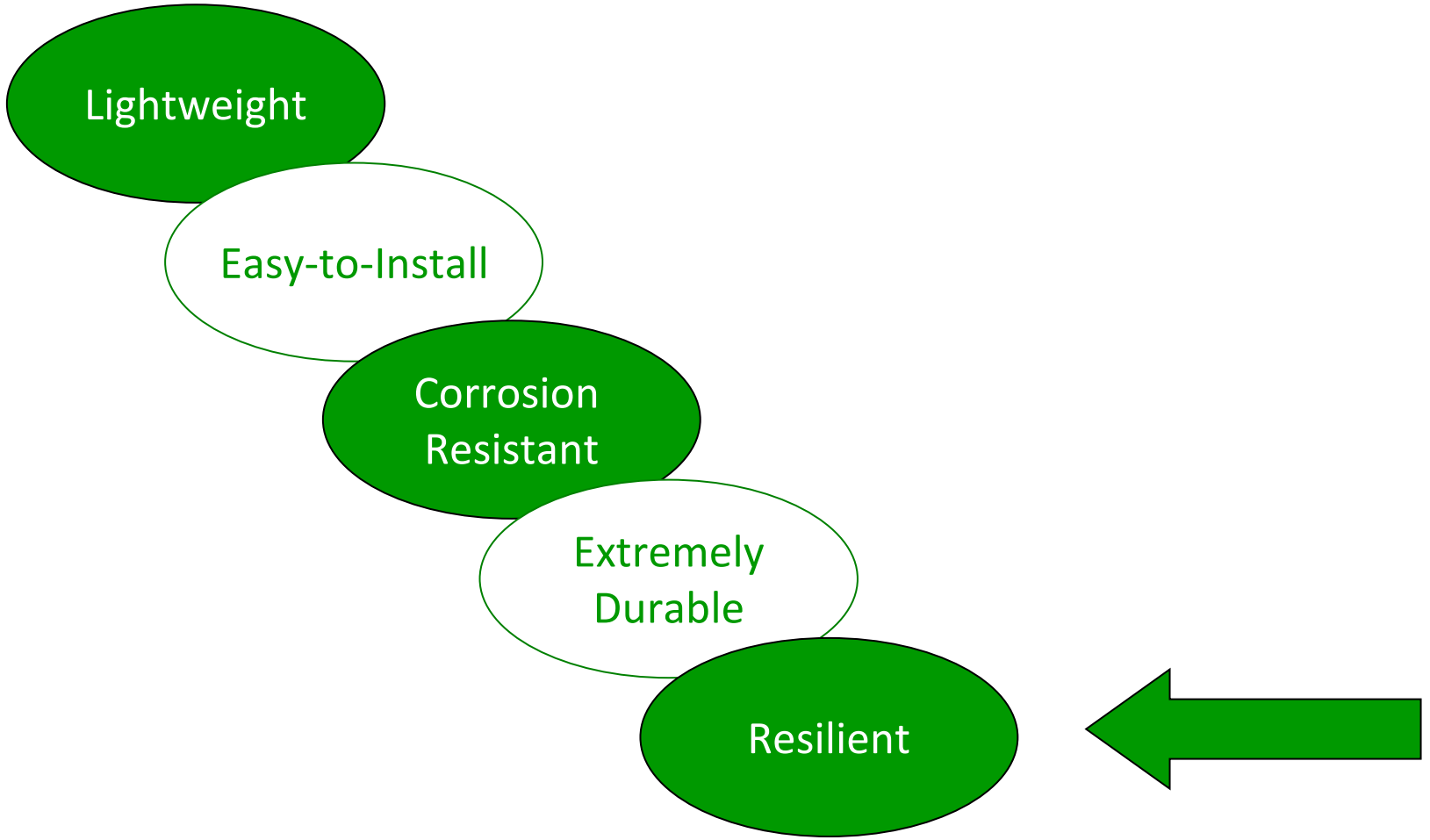
Waterfront / Coastal Applications of FRP Composites

- FRP composites are much more durable than wood in waterfront and coastal applications

*Jamestown – Scotland Ferry, Virginia

Attributes	Lightweight	Easy-to-Install	Corrosion-resistant	Extremely durable	Resilient

Key Attributes of FRP Composites for Infrastructure Applications



Resiliency of FRP Composites

- FRP composites are resistant to damage from natural disasters
  - Hurricanes, storm surge
  - Tornados
  - Earthquakes, fires

Dune restoration in Florida after Hurricane Matthew

Seawall in New York built after Hurricane Sandy

Attributes	Lightweight	Easy-to-Install	Corrosion-resistant	Extremely durable	Resilient

Resiliency of FRP Composites

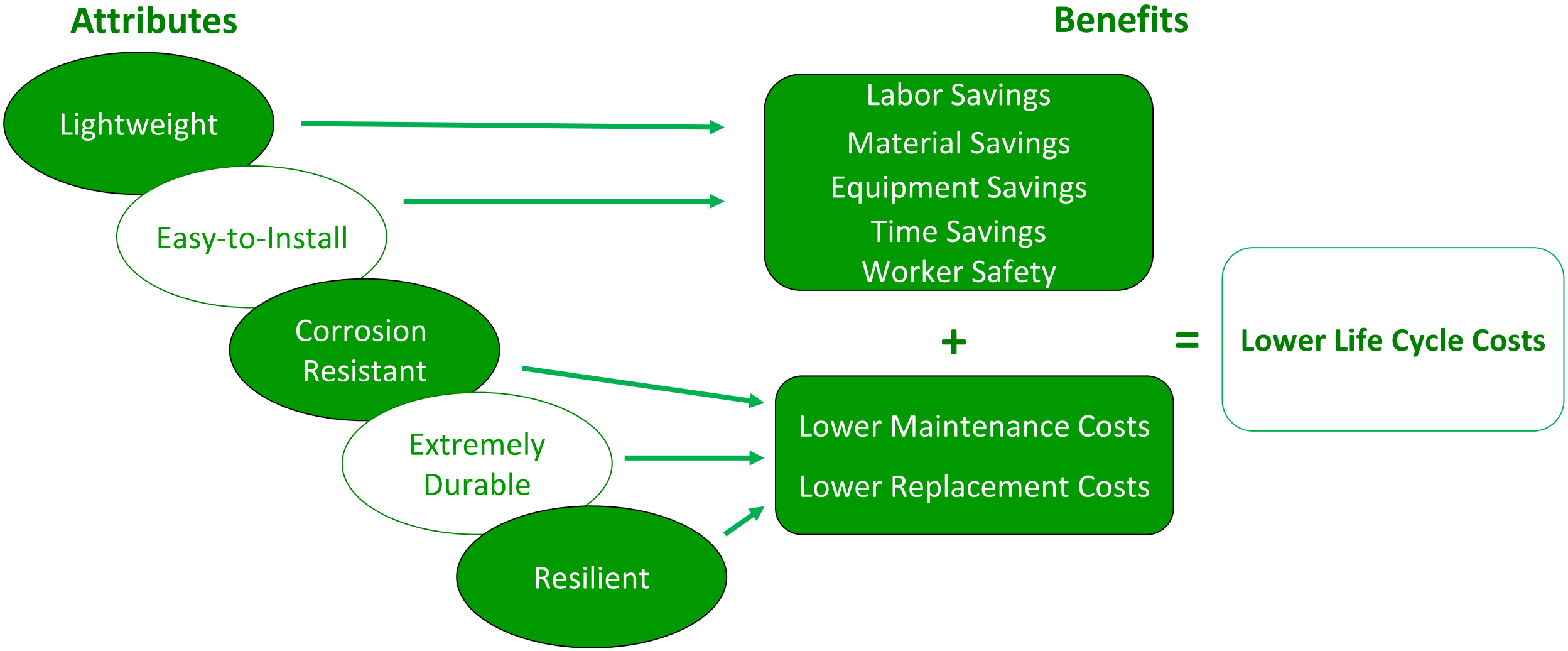
- FRP utility poles have survived hurricanes and forest fires

Composite Utility Pole Survives Forest Fire

nberly Hoodin November 14, 2019

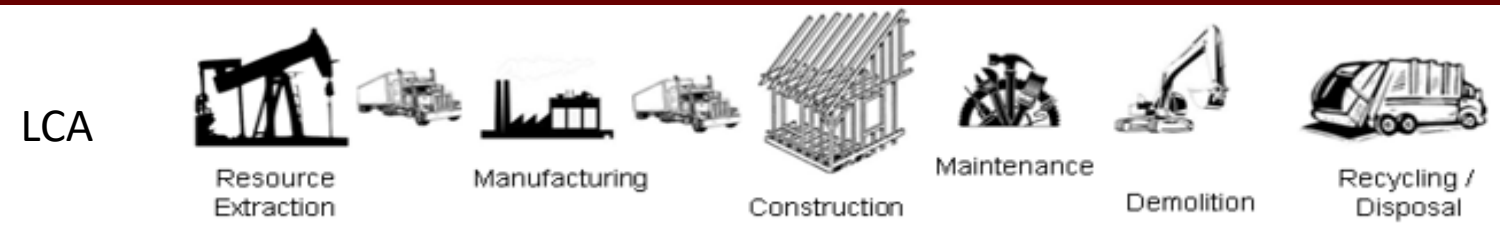
Attributes	Lightweight	Easy-to-Install	Corrosion-resistant	Extremely durable	Resilient

Attributes & Benefits of FRP Composites for Infrastructure Applications



Life Cycle Cost Considerations

Total Life Cycle Cost Analysis is similar to Life Cycle Assessment (LCA)



Total Cost = Raw Materials & Manufacturing + Construction & Installation + Operations & Maintenance + Replacement & End-of-Life

FRP composites can be more costly to purchase

They are low weight, resulting in lower cost to transport and install

Composites typically require less maintenance

Durability results in low replacement frequency

Life Cycle Cost Analysis

Advances in Civil Engineering Materials

Thomas Cadenazzi,[1] Giovanni Dotelli,[2] Marco Rossini,[3] Steven Nolan,[4] and Antonio Nanni[3]

DOI: 10.1520/ACEM20180113

Life-Cycle Cost and Life-Cycle Assessment Analysis at the Design Stage of a Fiber-Reinforced Polymer-Reinforced Concrete Bridge in Florida

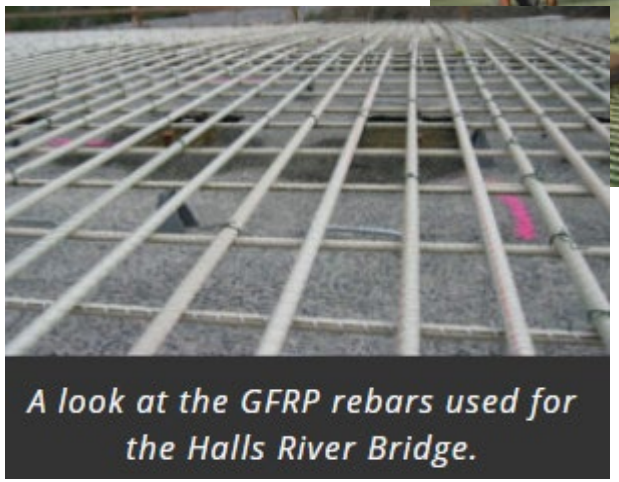
- Halls River Bridge in Homosassa, FL north of Tampa
- Continuous deck with 5 spans
  - 186’ long, 58’ wide
- Completed in November 2019

Benefits	Lightweight	Easy-to-Install	Corrosion-resistant	Extremely durable	Resilient	Lower Life Cycle Costs

Halls River Bridge Replacement

- Owner: Citrus County
- Designer: FDOT
- Funding: FHWA

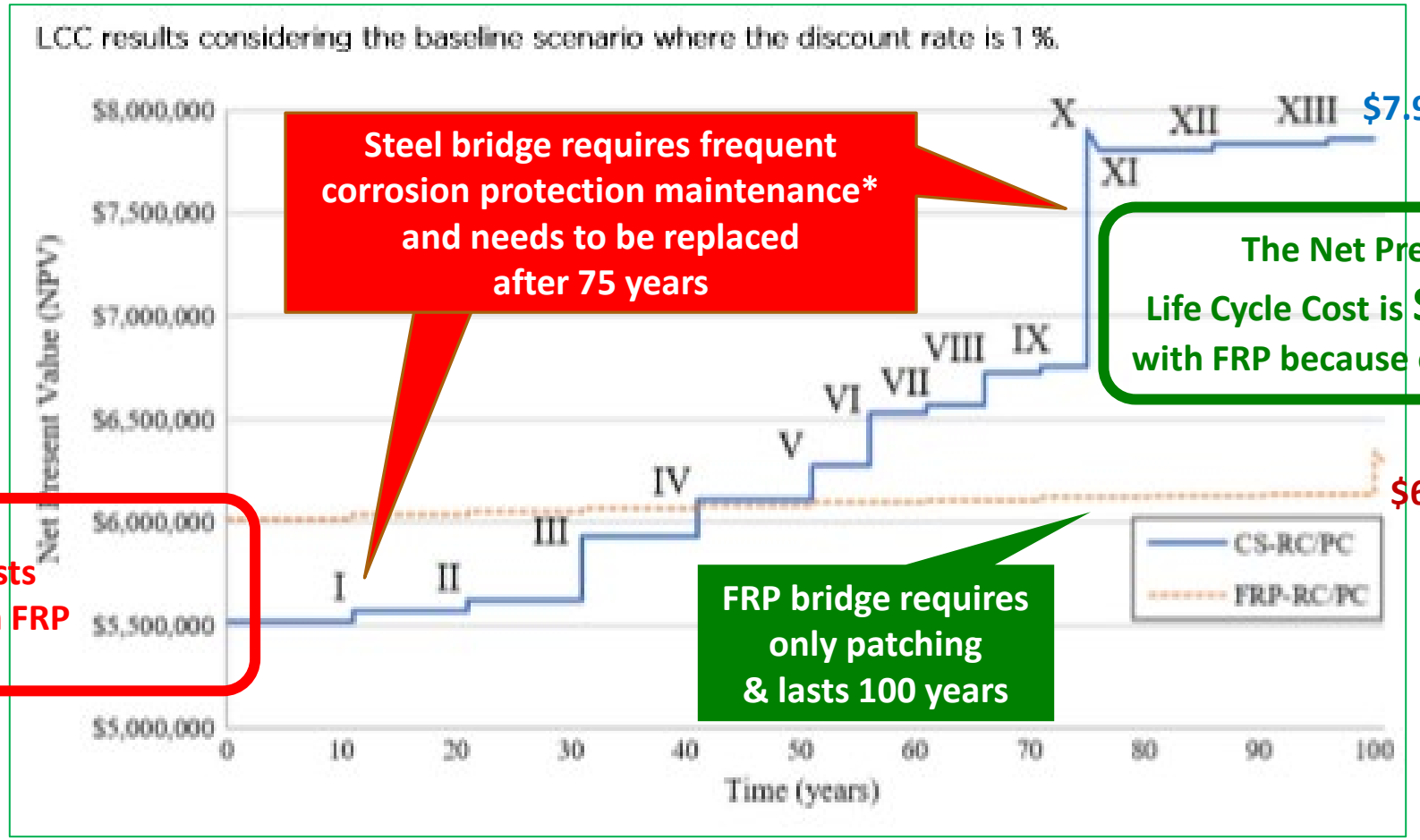
- Experimental project using innovative materials for the superstructure, substructure & sheet pile walls
- Uses GFRP- and CFRP- reinforced elements:
  - GFRP-RC bridge deck, pile bent caps, bulkhead caps, traffic railings and approach slabs
  - CFRP-PC bearing piles
  - CFRP-PC/GFRP-RC sheet piles
  - Hybrid HSCS-PC/GFRP-RC sheet piles



A look at the GFRP rebars used for the Halls River Bridge.

Benefits	Lightweight	Easy-to-Install	Corrosion-resistant	Extremely durable	Resilient	Lower Life Cycle Costs

Life Cycle Cost Analysis (LCCA) of the Halls River Bridge: Higher Upfront Cost but **Lower Life Cycle Cost**



Steel bridge requires frequent corrosion protection maintenance* and needs to be replaced after 75 years

$7.9 M

The Net Present Value of the Life Cycle Cost is $1.6M (20%) lower with FRP because of reduced maintenance

$6.3 M

Initial construction costs are $0.5M higher with FRP

FRP bridge requires only patching & lasts 100 years

Higher CAPEX

Lower OPEX

**Life-365 software used to develop the maintenance and repair schedule*

Benefits	Lightweight	Easy-to-Install	Corrosion-resistant	Extremely durable	Resilient	Lower Life Cycle Costs

An Example of Lower Upfront Costs

- Replacement of the Tide Mill Bridge in Edmunds, ME using “Bridge in a Backpack” technology developed at U Maine
- Installed Cost (Materials + Engineering) with FRP was 50% lower than CON/SPAN®

	Cost ($)
FRP arches & decking	**398,000**
CON/SPAN® (modular precast concrete)	**750,000**

- One phase construction with FRP
- The use of FRP arches in place of steel rebar provides improved corrosion resistance and reduces maintenance costs

Lower CAPEX

Lower OPEX

More Examples of Lower Installed Costs

- Pultruded GFRP used for permitted, primary structures
- 10-30% lower installed cost than steel
  - Vertical integration helps lower costs
    - Fabrication + installation

Mechanical support mezzanine

Screen wall

Pipe rack

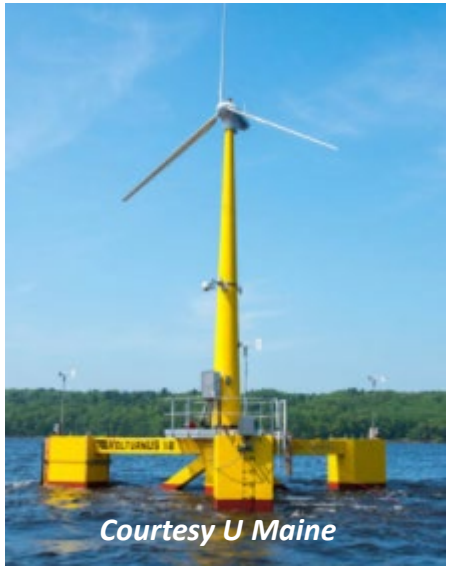
Lower CAPEX

Lower OPEX

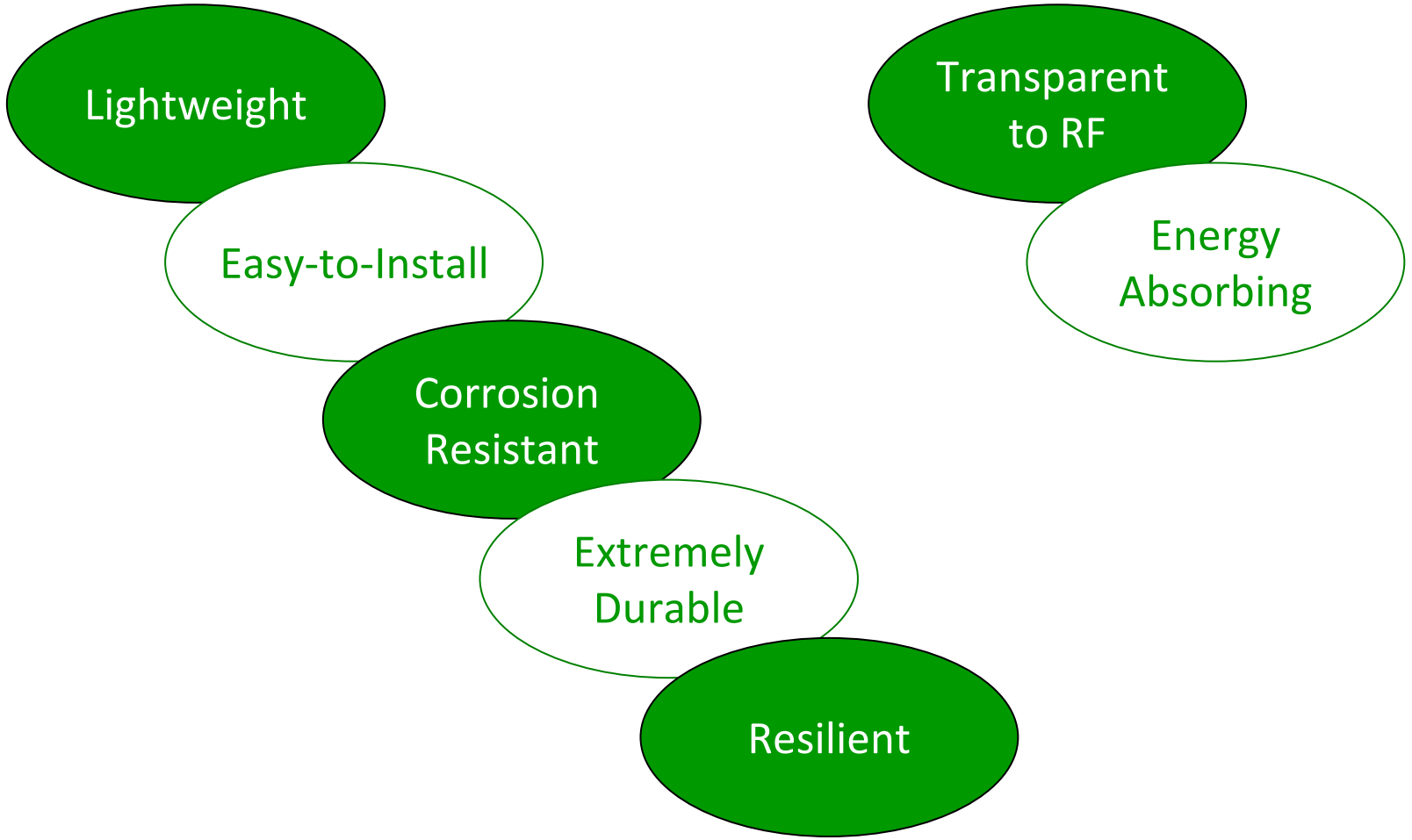
All pictures courtesy of Advantic

Sustainability Considerations

- **Energy-savings:** Lightweight FRP composites require less energy to transport and install
- **Material savings:** Durable FRP composites do not need to be replaced as frequently
- **Lower Emissions:** 8% of CO_2 emissions come from cement production. FRP can replace concrete. FRP rebar can make it last longer.
- **End-of-life:** Cost-effective recycling solutions are being developed to recover and re-use the fibers and the resins
- **Energy-enabling:** FRP blades and towers enable sustainable wind energy on-shore and off-shore

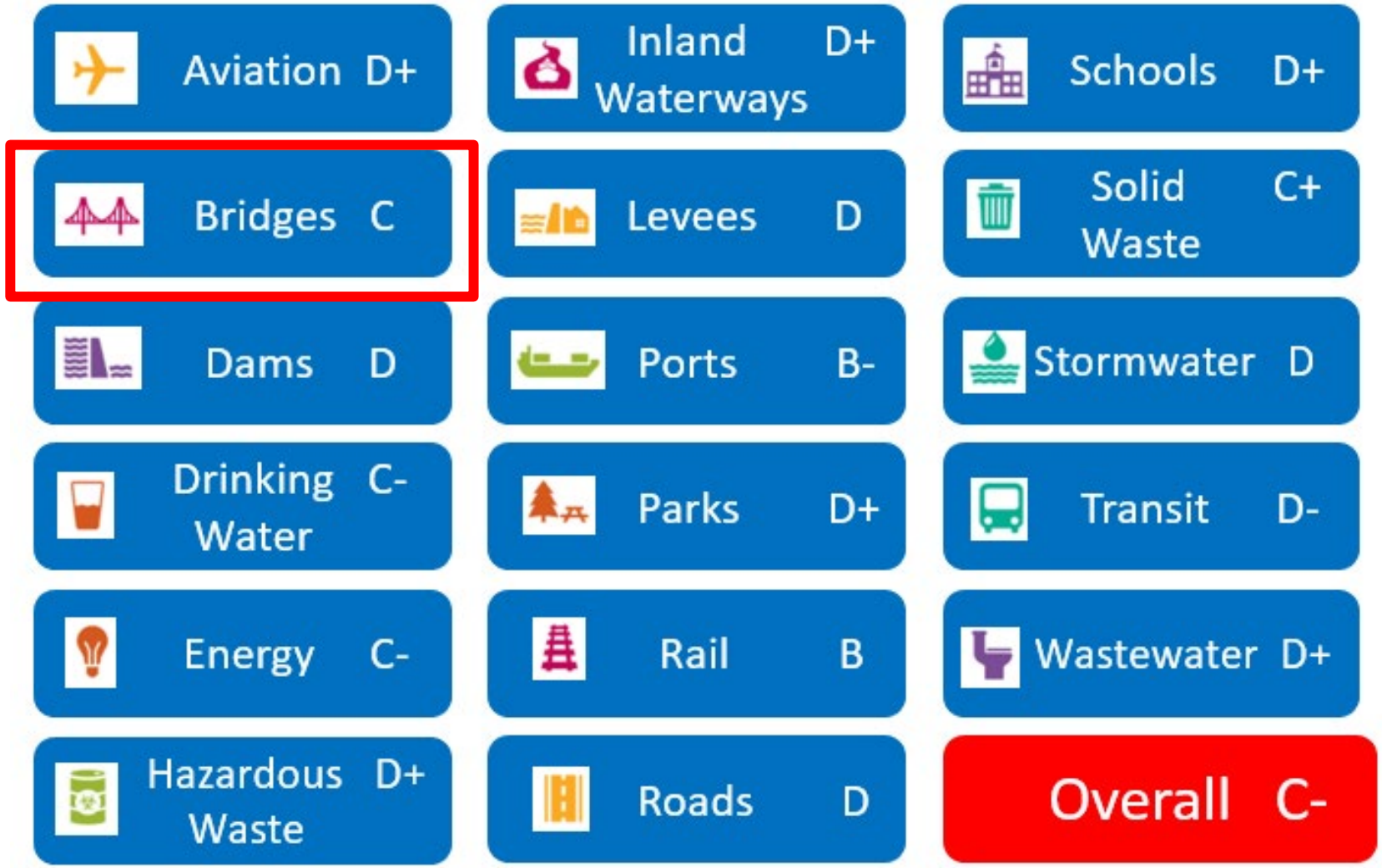


Other Important Attributes of FRP Composites



Connecting FRP Composites to ASCE's Infrastructure Report Card

Many Opportunities for Improvement



Bridge Construction

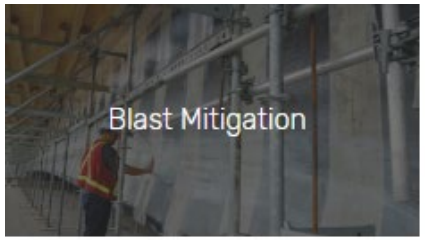
- More than 500 bridges have been constructed with FRP composites and/or FRP rebar-reinforced concrete
- 22 states and Canada

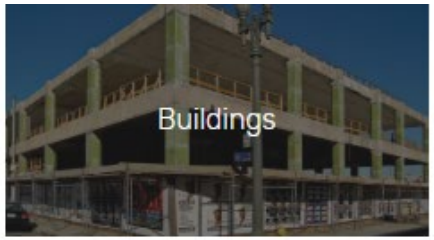
Courtesy of Advanced Infrastructure Technologies

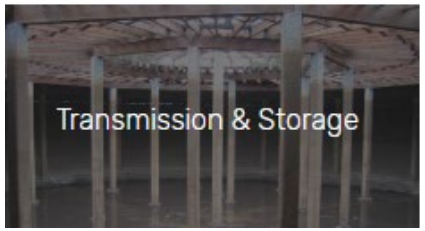
Strengthening of Bridges

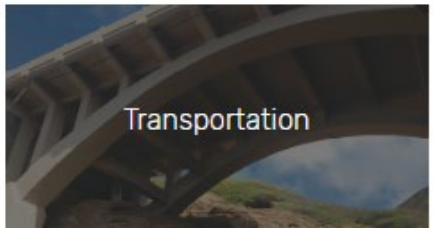
- FRP wraps have been used to strengthen and repair bridges
  - Usually CFRP
  - Improved resistance to earthquakes

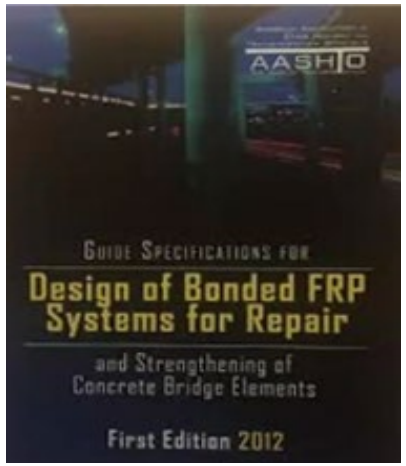
- Other examples of FRP strengthening











Column strengthening

Pedestrian Bridges and Walkways

- Pedestrian bridges are lightweight and durable

- Plans are underway to add a pedestrian walkway to the famous Newport RI bridge
  - Lightweight addition to an existing structure

Indian Lake, Ohio

Lake Tahoe

More Opportunities for Improvement

Inland Waterways, Dams & Levees

Inland Waterways D+

Dams D

Levees D

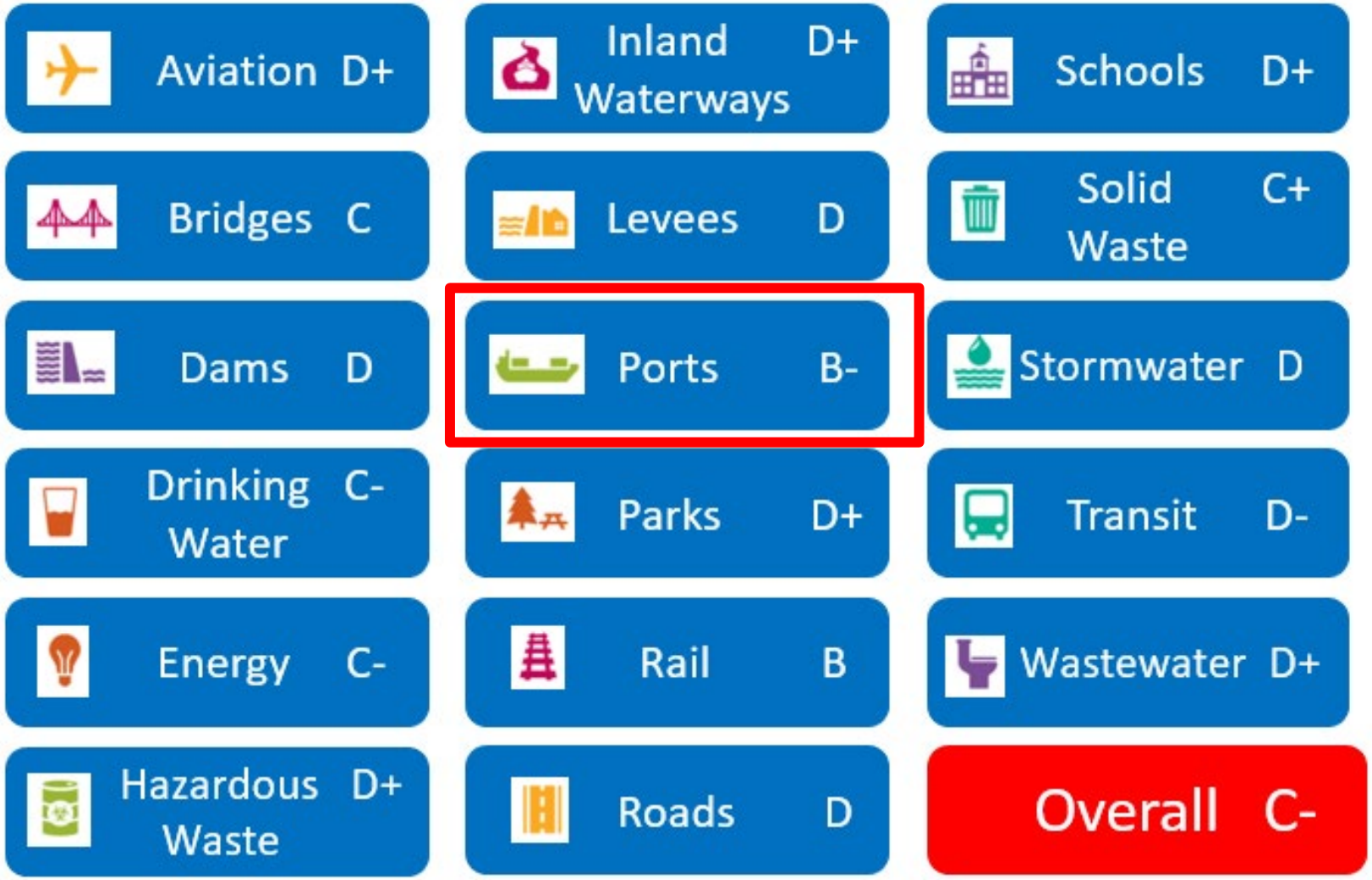
FRP Locks

FRP Wicket Gates

Bridge Protection

Navigation Aids with FRP Piles

More Opportunities for Improvement



Ports

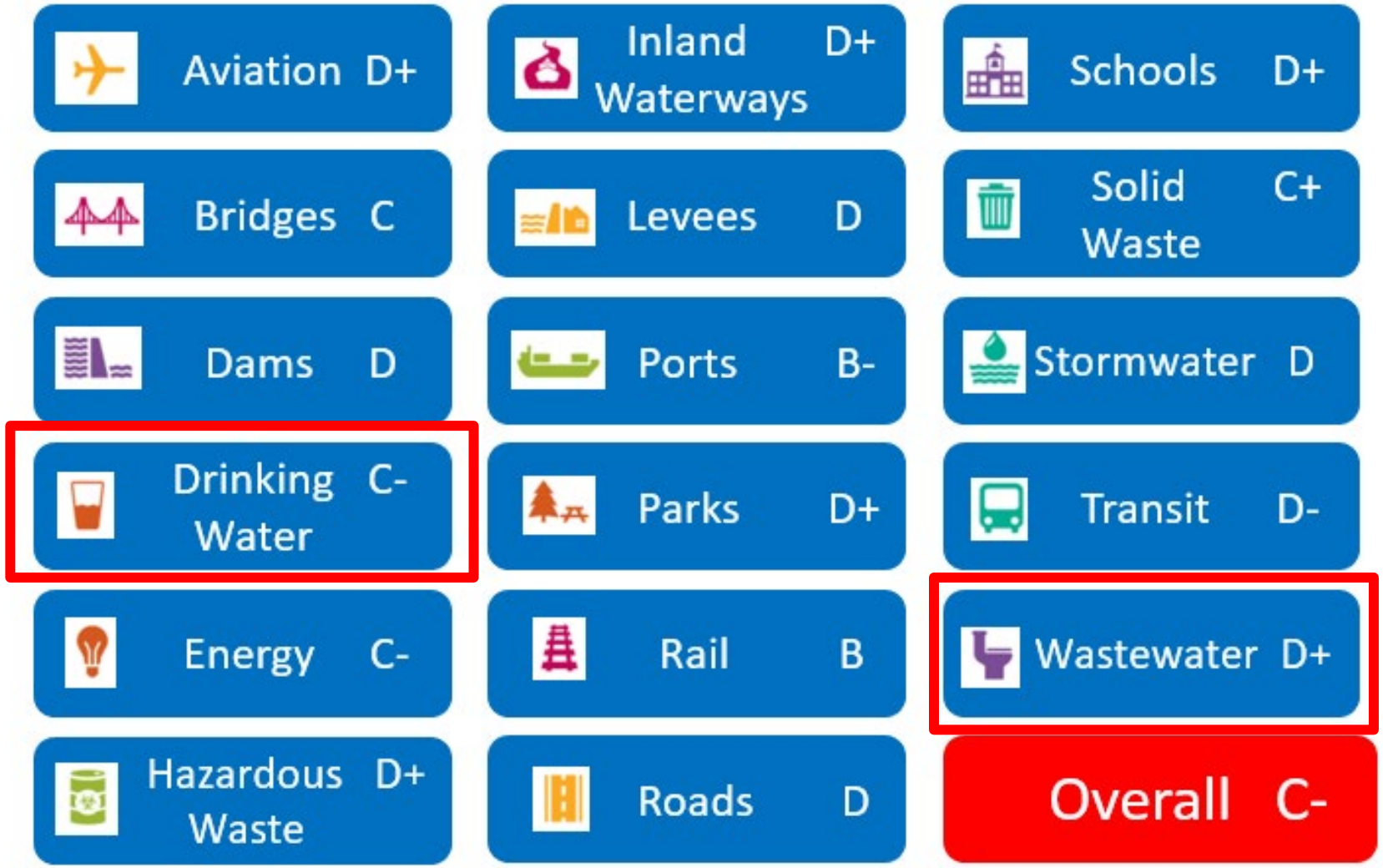
Piers

Bilge

Fender

Docking

More Opportunities for Improvement



Negative Impacts of Aging Water Infrastructure

- Loss of drinking water
  - 6 billion gallons of treated water per day!
- Contamination of drinking water
  - Leaching of lead from pipes
- Water main bursts
  - > 250,000 per year
  - Damage & disruption

NEW YORK

Massive water main break floods NYC neighborhood around Lincoln Center

By BRITTANY KRIEGSTEIN, CLAYTON GUSE, WES PARNELL and ANNA SANDERS
NEW YORK DAILY NEWS | JAN 13, 2020 | 2:02 PM

NEWS

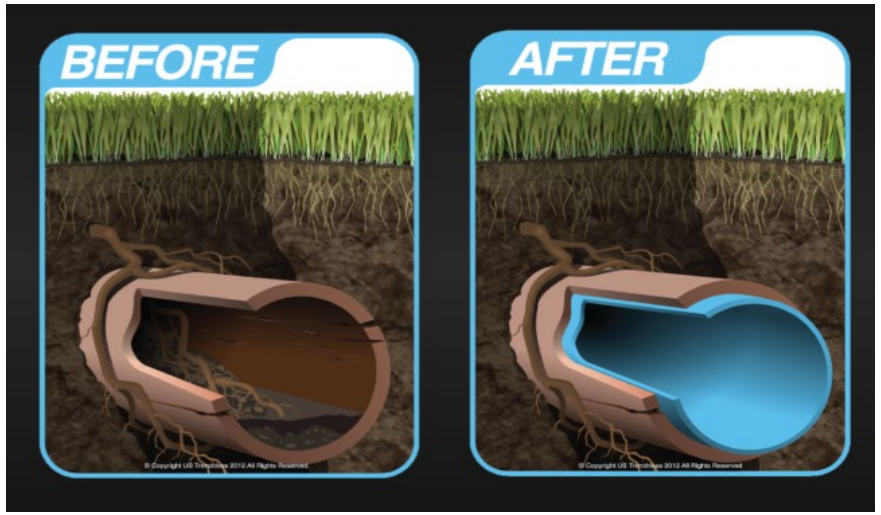
Houston main break causes chaos, strands people in rising water

By Joshua Rhett Miller
February 28, 2020 | 10:19am | Updated

Improving Water Infrastructure with FRP

Drinking C-Water

- Drinking Water
  - Pipes suitable for potable water
    - Corrosion-resistant, no lead
    - Pass NSF 61
- Repair of pipes
  - Trenchless repair with Cured-in-Place Pipe (CIPP) and liners

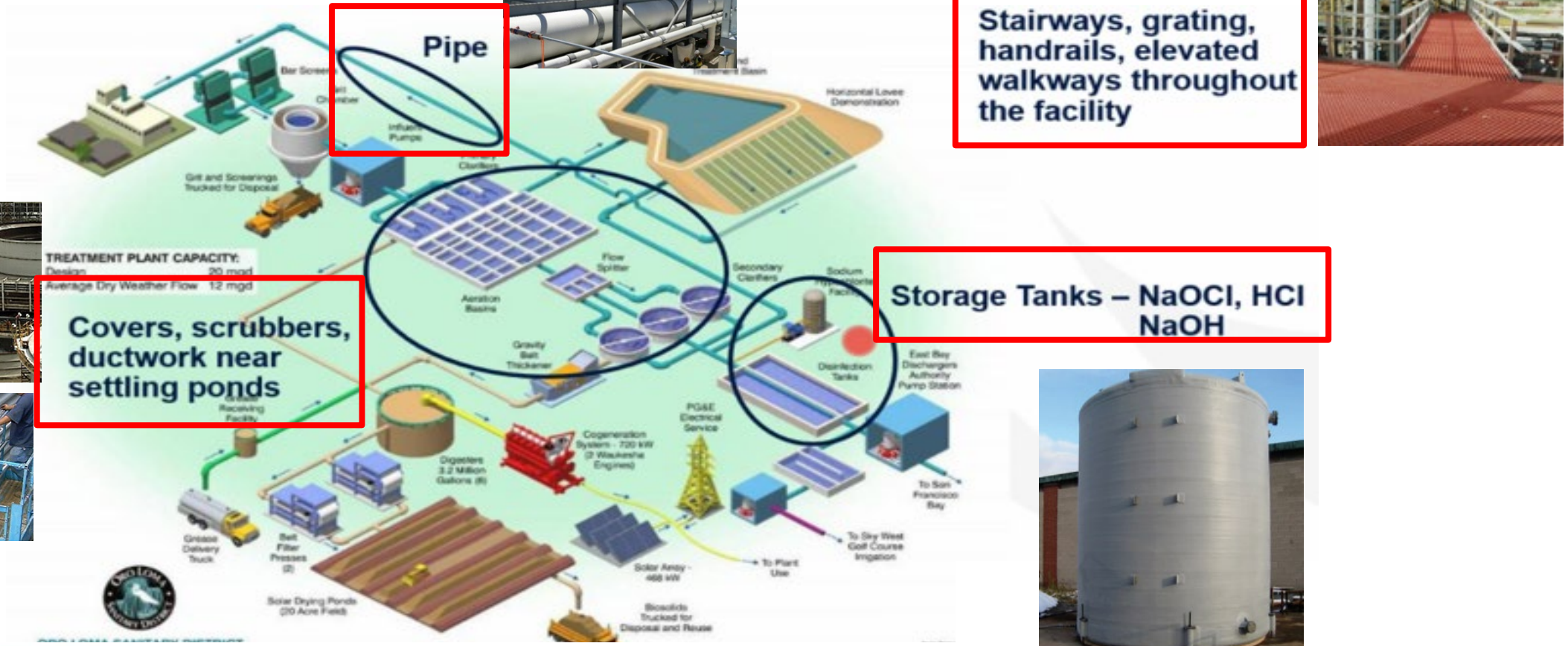


Improving Wastewater Infrastructure with FRP

Wastewater D+

- Corrosion-resistant FRP can be used with bleach, strong acids and strong bases in wastewater treatment plants

Pipe



Stairways, grating, handrails, elevated walkways throughout the facility

Covers, scrubbers, ductwork near settling ponds

Storage Tanks – NaOCl, HCl NaOH

All pictures courtesy of INEOS Composites

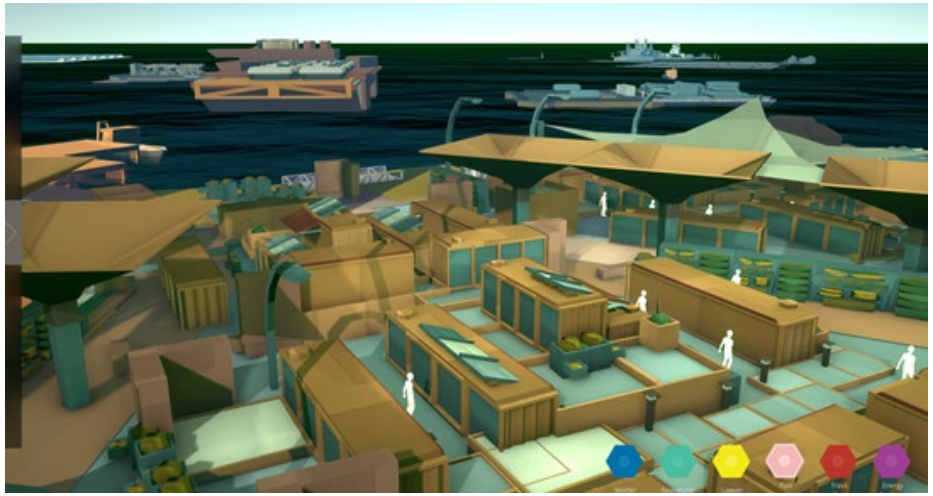
To Summarize ….

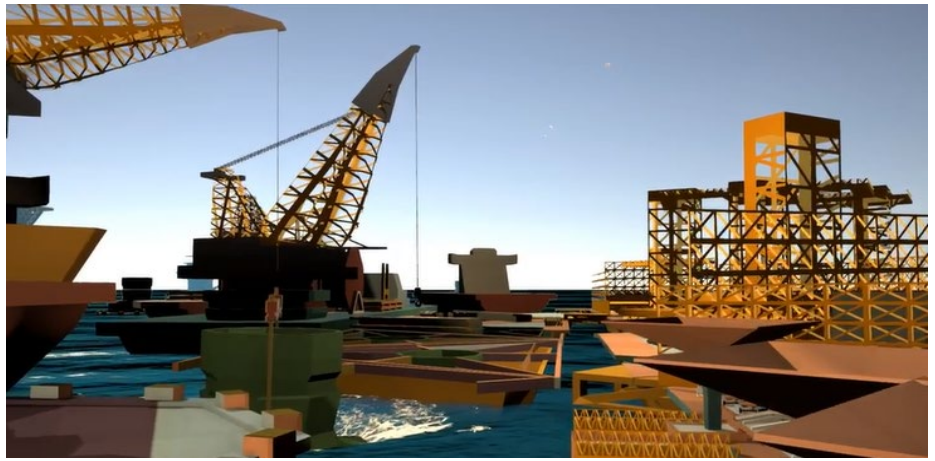
- There is an extremely good fit between FRP composites and our nation's infrastructure needs, **today** and in the future

Connecting FRP Composites to ASCE's Future World Vision

https://www.futureworldvision.org/future-worlds/floating-city#:~:text=Created%20using%20Future%20World%20Vision%27s%20combination%20of%20future-scenario,as%20rising%20sea%20levels%20threaten%20coastal%20city%20flooding.

Screen Shots from the Video

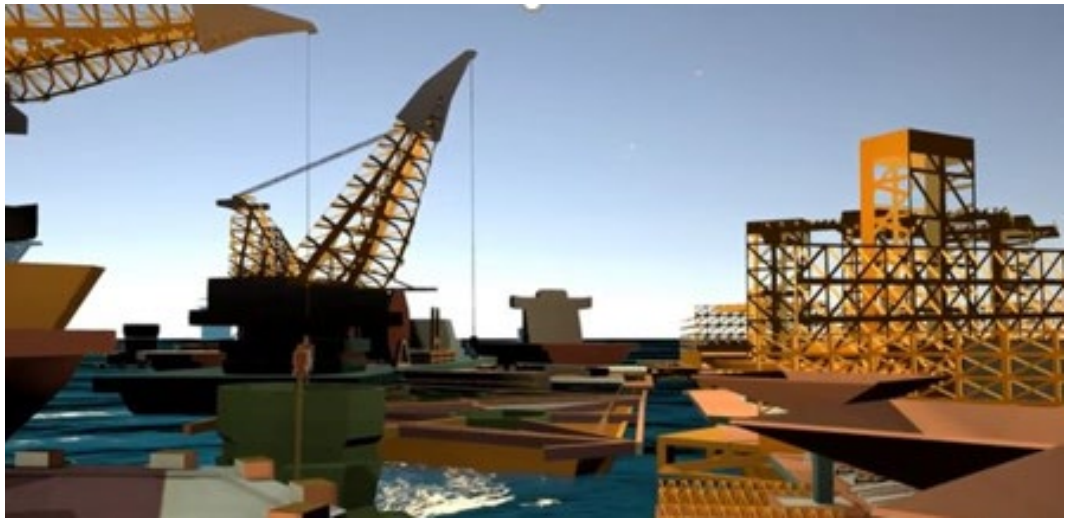


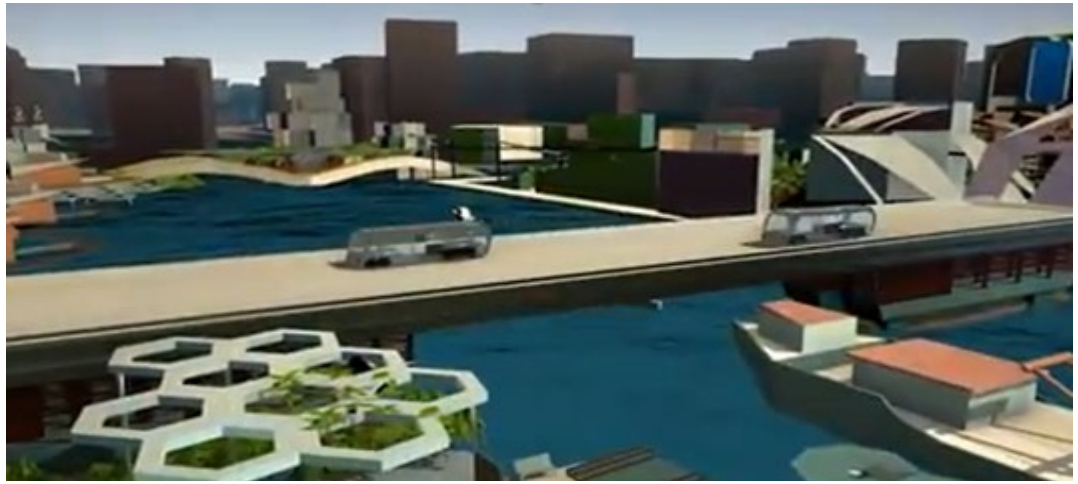


Using FRP Composites in Floating Cities

Imagine if everything on top of the water was lighter !

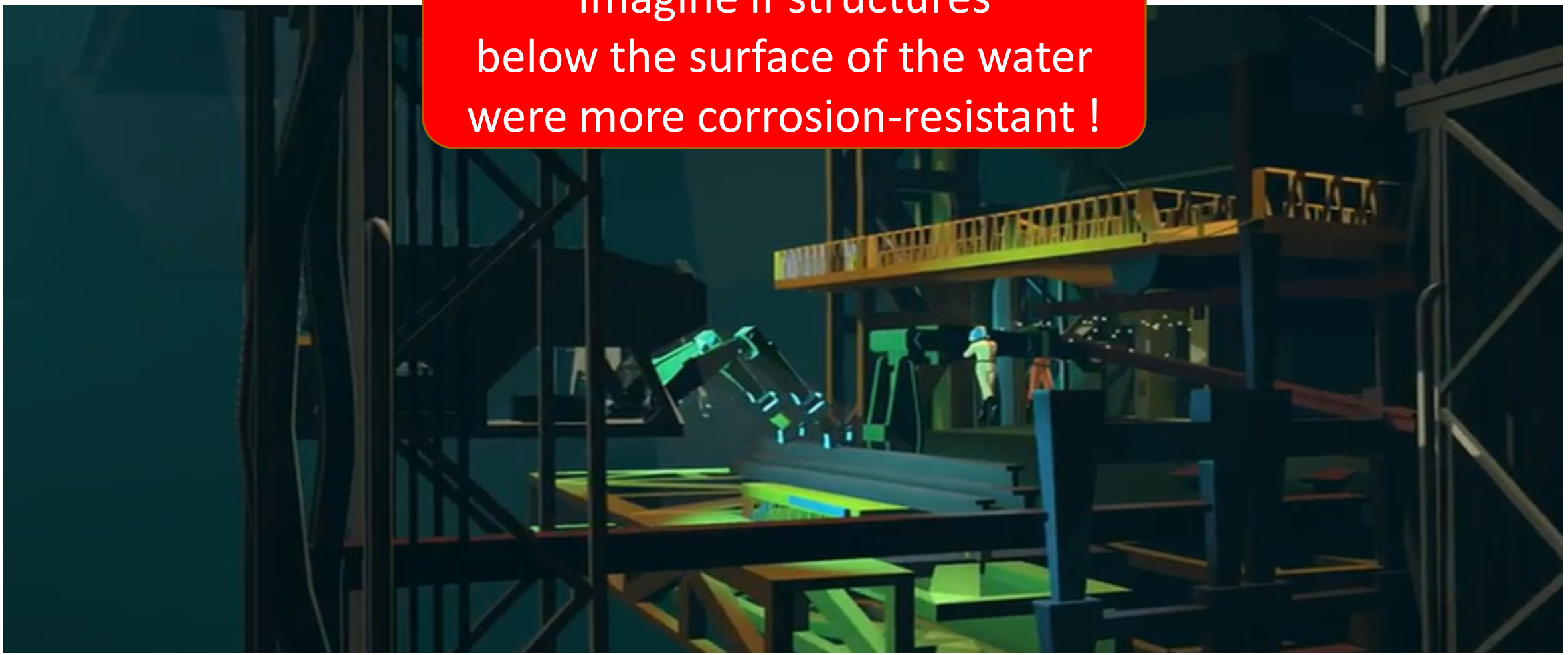
- FRP composites 30% lighter than concrete
- FRP rebar – 1/3rd the weight of steel
- Building facades, pedestrian bridges …..





Using FRP Composites Underneath Floating Cities

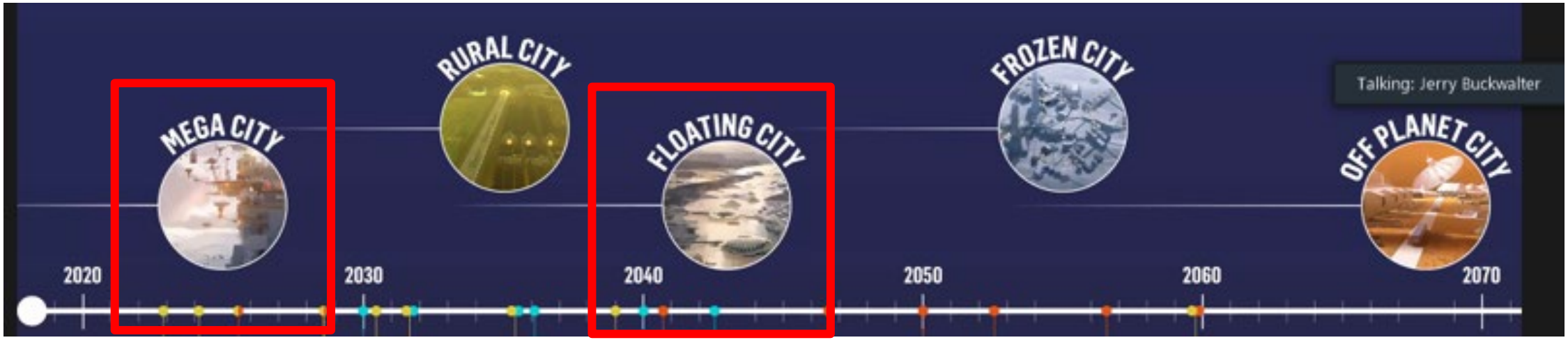
Imagine if structures
below the surface of the water
were more corrosion-resistant !



Using FRP Composites Around Floating Cities

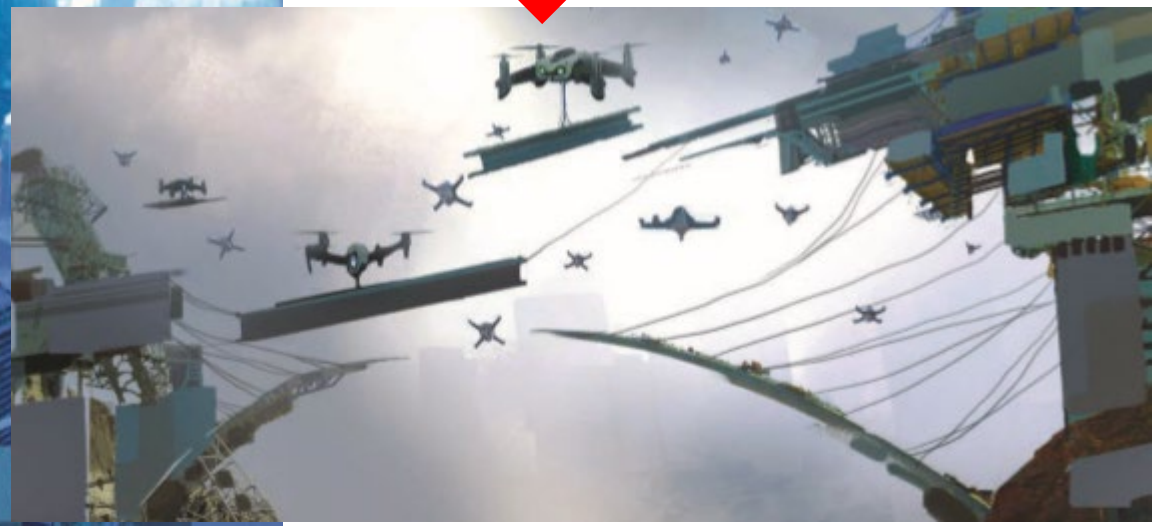
Consider the widespread use
of FRP composites
in waterfront & coastal applications

Using FRP Composites in Other *Future World Vision* Scenarios



Using FRP Composites in Other *Future World Vision* Scenarios

FRP composites will be used for Urban Air Mobility in megacities



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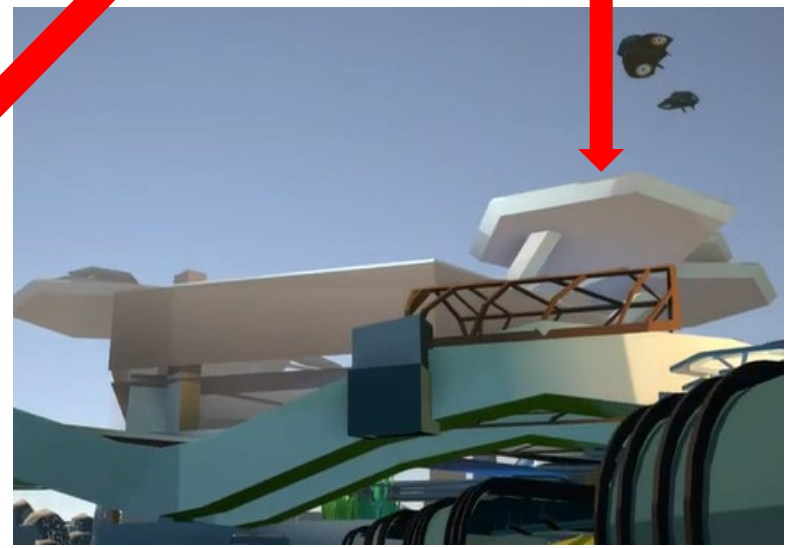
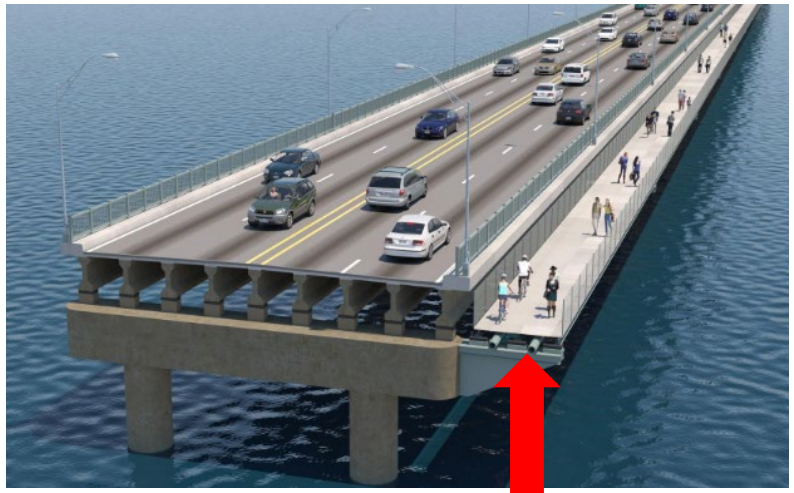
Using FRP Composites in Megacities

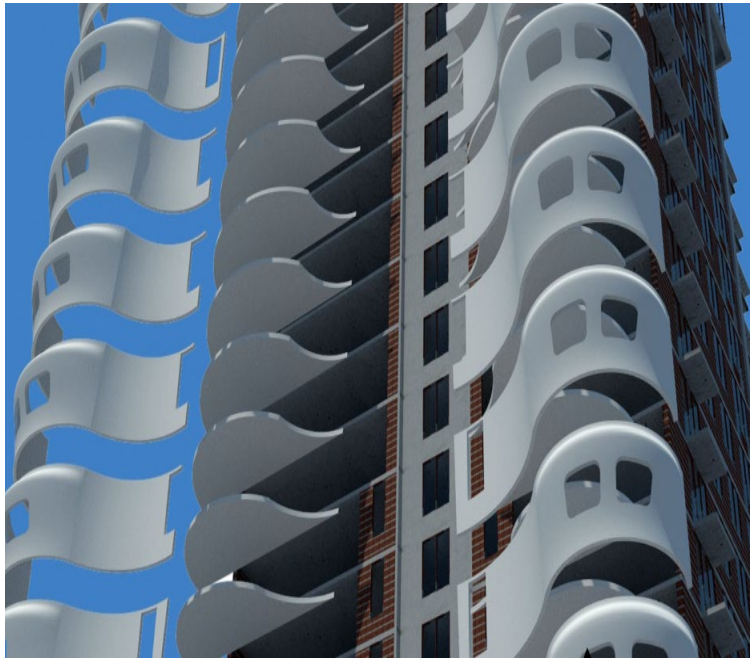
FRP composites can be used for heliports in megacities



Creating Additional Space Without Adding Much Weight



Recall that this walkway can be added to the existing bridge structure without adding too much weight



"Inhabitable Skin" Concept: CRAFT Engineering Studio

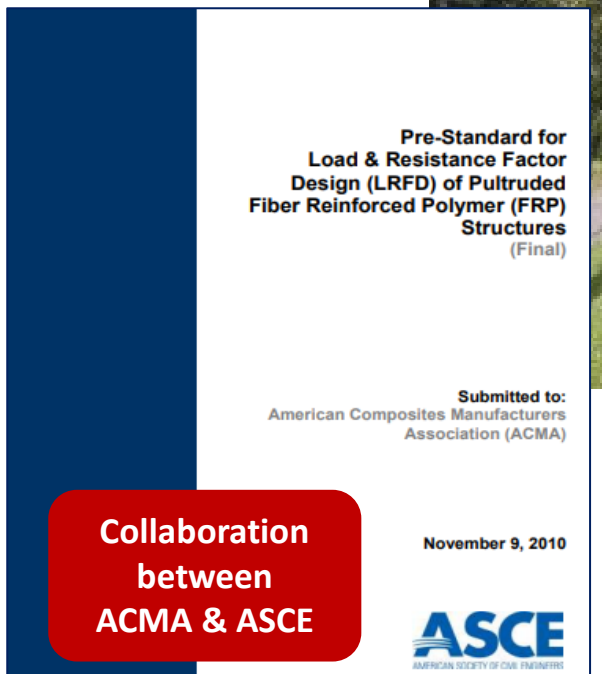
Similarly, lightweight composite could be used to add floor space to an existing building

Using FRP Composites for 5G Communication in Smart Cities

- Many more antennas will be needed for communication in megacities with 5G
- FRP composites are transparent to the high frequency, short wavelength radiation for 5G
  - 24-86 GHz (RF, mmWave)
- FRP composites can be used to improve communication between buildings and within buildings
  - Antenna radomes, shrouds and tubes
  - Signage
  - Building facades
  - Curtain wall frames

Using FRP Composites for 5G Communication

- "Smart" FRP light poles are being developed for 5G communication
  - www.luxturrim5G.com
- Pultruded FRP products are ideal for 5G applications
  - Poles
  - Tubes
  - Panels



Collaboration between ACMA & ASCE

Lux Turrim 5G smart poles

Using FRP Composites in Other *Future World Vision* Scenarios

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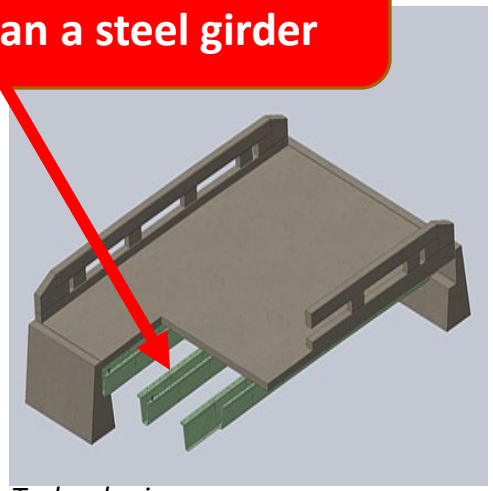
Using FRP Composites in Other *Future World Vision* Scenarios

"Modular construction may be made faster and more efficient by shop-fabricated pieces delivered to jobsites by drones"

This FRP bridge girder is 70% lighter than a steel girder



Courtesy of The University of Maine & Advanced Infrastructure Technologies

Modular construction:
Pre-fabricated walls for a composite foundation are easy to install

Courtesy of Composite Panel Systems

Take-Home Message & Next Steps

Take-Home Message

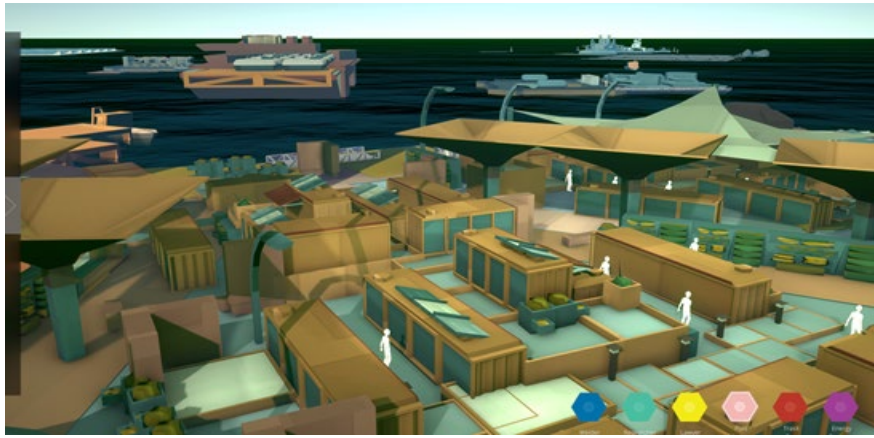
There is an extremely good fit
between FRP composites
and our nation's infrastructure needs,
today and in the future.

Today

Aviation D+	√ Inland Waterways D+	Schools D+
√ Bridges C	√ Levees D	Solid Waste C+
√ Dams D	√ Ports B-	Stormwater D
√ Drinking Water C-	Parks D+	Transit D-
Energy C-	Rail B	√ Wastewater D+
Hazardous Waste D+	Roads D	Overall C-

FRP composites can help civil engineers solve many of our nation's infrastructure needs

…and in the future



…. FRP composites can help civil engineers create the infrastructure of the future

Next Steps

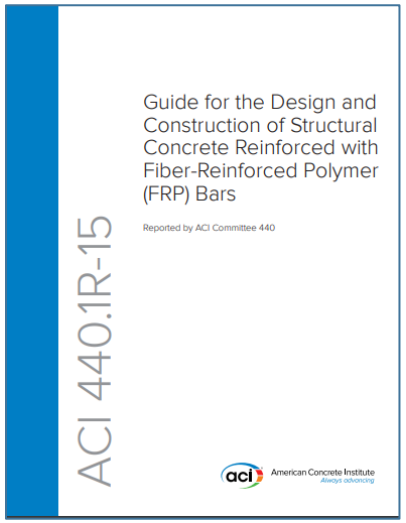
If you want to learn more ….

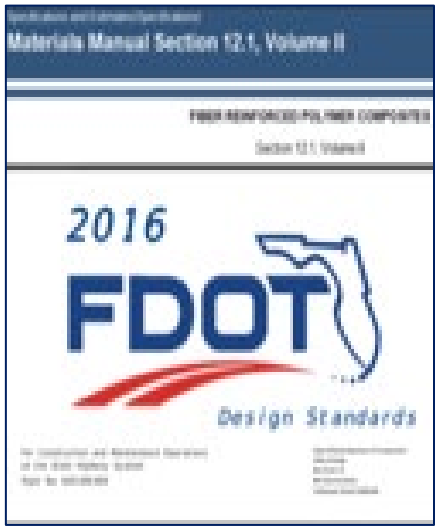
- You can listen to the next 3 days of programming
  - Tuesday — Transportation & Waterfront Structures — End User Panel
  - Wednesday — Buildings & Industrial Structures — LRFD Design Standard
  - Thursday — Sustainability, Resiliency & Design — End User Panel

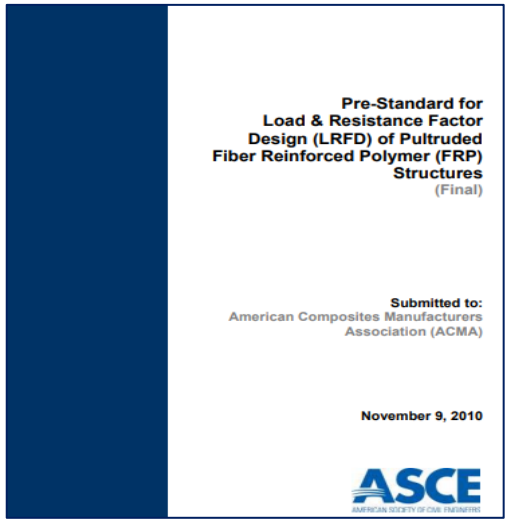
- You can visit www.discovercomposites.com to learn more about the use of FRP composites in Infrastructure applications

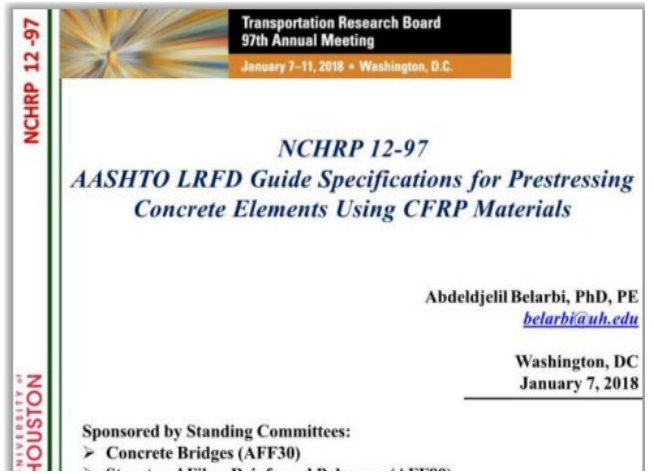
If You Want to Learn More…….

- You can visit the ACMA "booth" in the Exhibitor section & download these documents:
  - **ANSI/ACMA Standards**
    - Fiberglass Grating Manual
    - FRP Composite Utility Poles
  - **Industry Guidelines**
    - Guidelines and Recommended Practices for Fiber Reinforced Polymer Architectural Products
    - Industry Recommendations for Installation and Maintenance of FRP Gratings
  - **References**
    - Summary of Standards Specification Codes for FRP Composites in Construction and Infrastructure
    - Report on FRP composites in WV Bridges
    - FDOT Case Studies overview by application
    - Summary of FRP Project Awards









Acknowledgments

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- Tony Nanni — University of Miami
- Steve Nolan — Florida Department of Transportation
- Scott Reeve — Composite Advantage
- Dustin Troutman — Creative Pultrusions

To Earn Your PDH Credit ….

- Click on the “Polls” icon on your screen
- Answer the questions about the content of this presentation

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