Icorr / NEIMME
Integrity Engineering for a Sustainable Future
June 22nd, 2023

carboline
Coatings - Linings - Fireproofing

Advances in Wind Blade Coating and Testing

Edvard Daehlen – Carboline

June 2023

Who We Are

WHOLLY OWNED SUBSIDIARY OF

RPM

RPM Affiliation

1947

Founded as Republic Powdered Metals, in 1947 by **Frank Sullivan Sr.**

Based in Medina, Ohio, Current CEO: **Frank Sullivan Jr.**

RPM

New York Stock Exchange Symbol

FY21 sales of **$6.1B**

48 consecutive annual cash dividend increases delivering approximately **$2.8B** in after tax capital to its shareholder's through capital dividend program

RPM Affiliation

4

Operating Groups

80% (824) institutional investors & **20%** (194,030) individuals

15,500 employees worldwide

124 manufacturing facilities in **22** countries

THE BEST HOME FOR ENTREPRENEURIAL COMPANIES

RPM Companies

CONSTRUCTION PRODUCTS GROUP

FY21 Sales: $2.1 billion - 34%

Create and drive unique solutions for the construction, restoration and maintenance of the building envelope

PERFORMANCE COATINGS GROUP

FY21 Sales: $1.0 billion - 17%

Protecting, decorating and extending the useful life of steel and concrete in industry + infrastructure

FY21 SALES:
$6.1 BILLION

CONSUMER GROUP

FY21 Sales: $2.3 billion - 38%

Create, innovate and lead consumer product category platforms

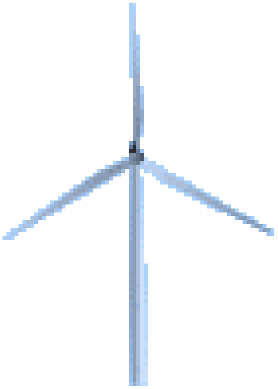
SPECIALTY PRODUCTS GROUP

FY21 Sales: $0.7 billion - 11%

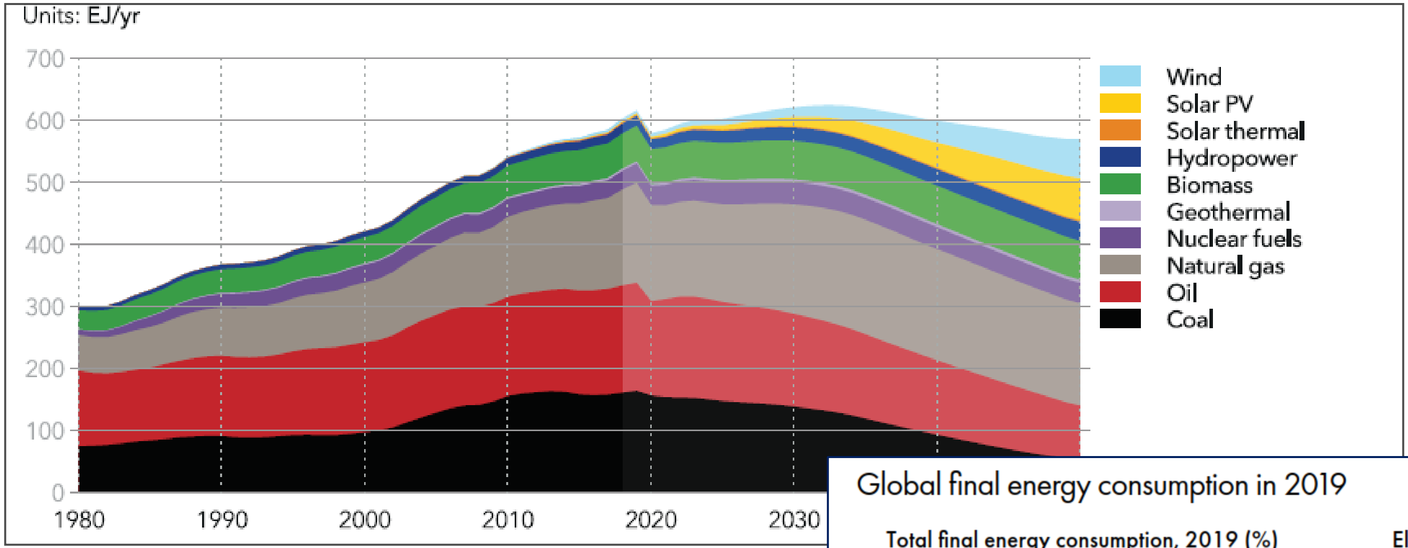
Best home for entrepreneurial companies and incubator of new market platforms

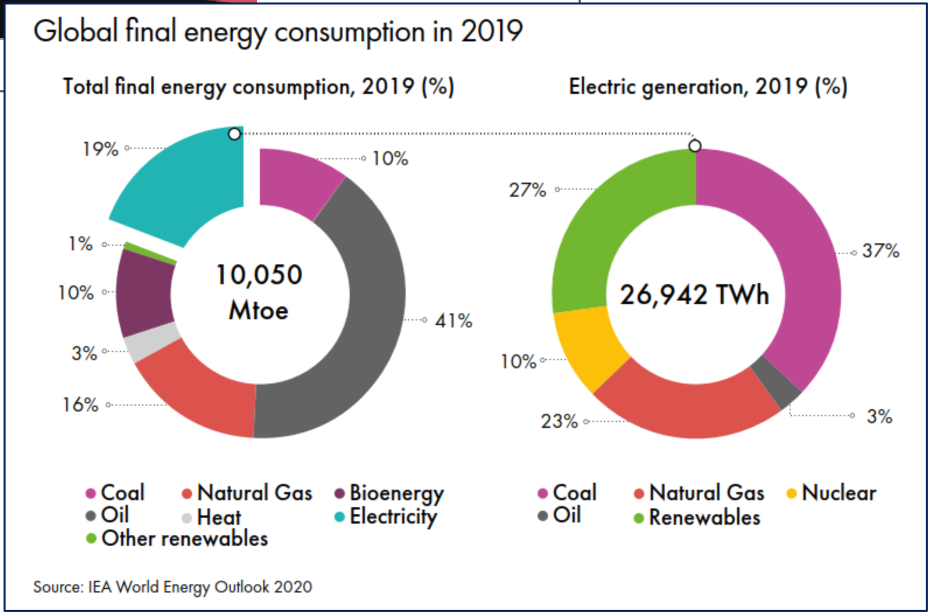
Carboline in Europe
R&D and manufacturing

- Spain
  - FireProofing
- Italy
  - Liquid Coating
- Norway
  - Liquid Coating and Epoxy based FireProofing
  - **Global R&D for Wind Turbine Blade Coating**

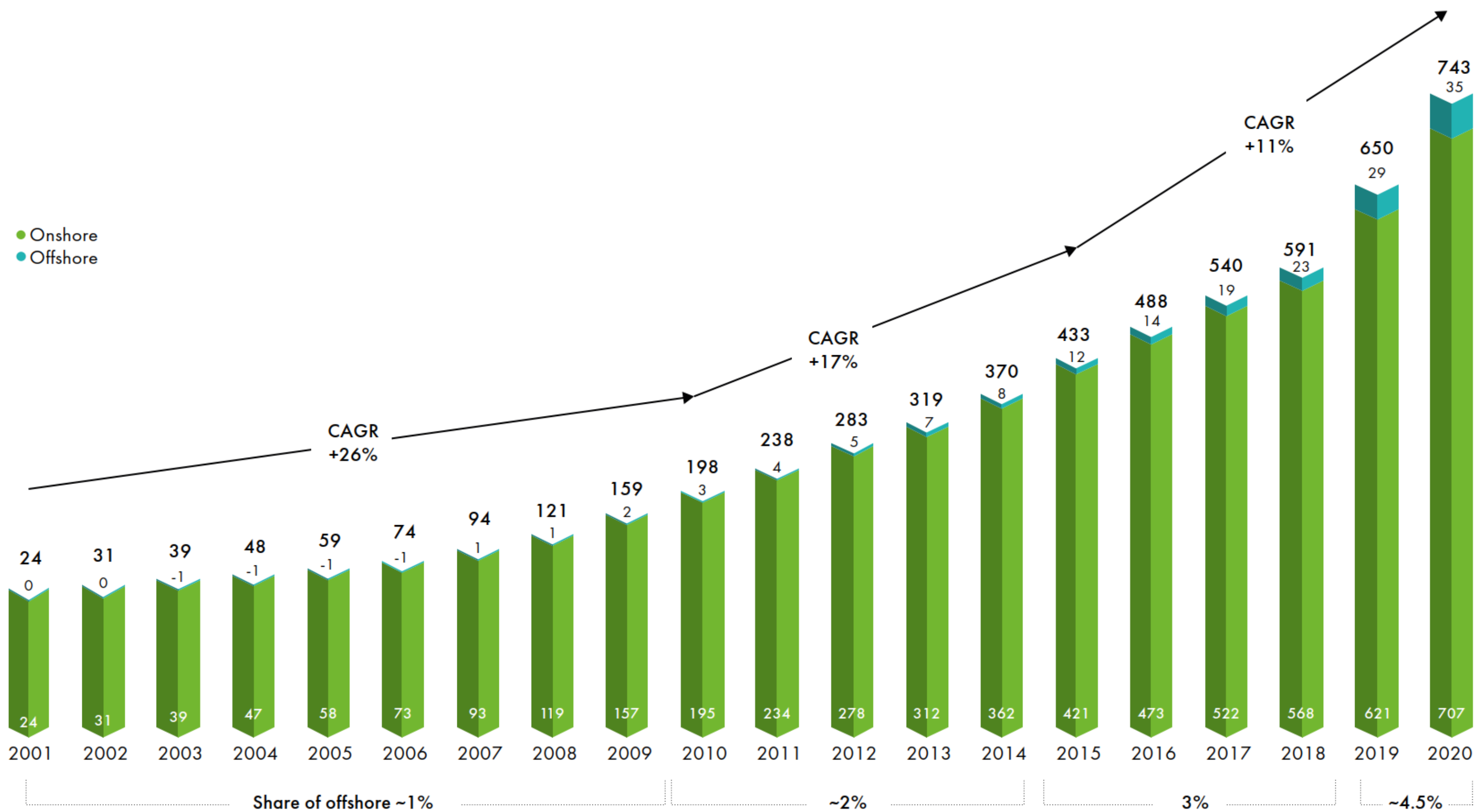


Changes in the energy marked
DNV-GL Outlook / IEA

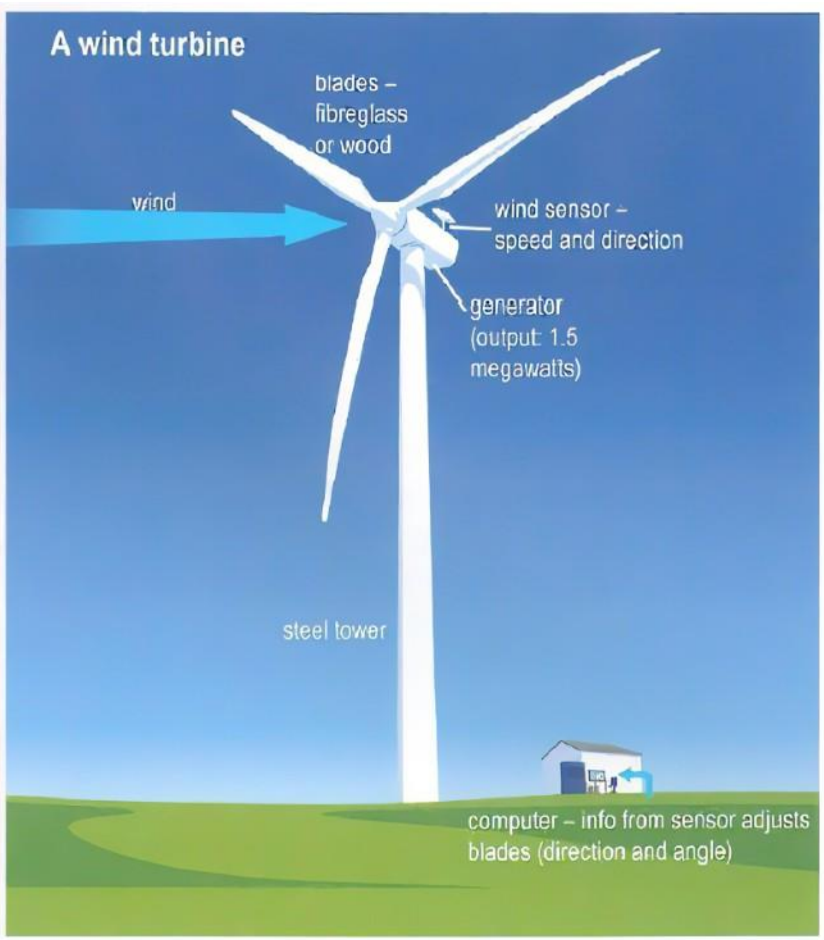


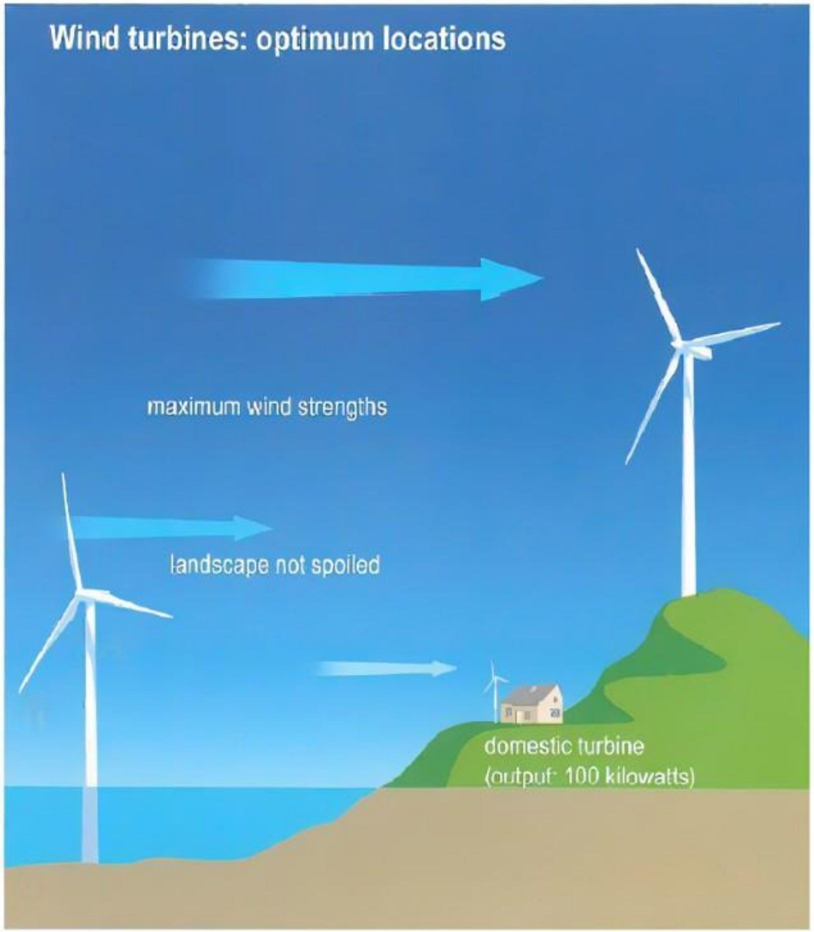


Wind Power
Historical development of total installation (GW)



Wind turbines – basic design





Similarities and differences between coating of steel and coating of wind turbine blades

- Protecting the substrate from deterioration / degradation
  - Steel → Corrosion
  - Blades → Erosion
- Increasing the lifetime of the object
- Preventing loss of energy (Annual Energy Output)
  - Blades → Smooth surface increase the annual energy output
  - Steel (Ocean going vessel) → Antifouling keep fuel consumption stable
- Giving colour to the object

Substrates and operation

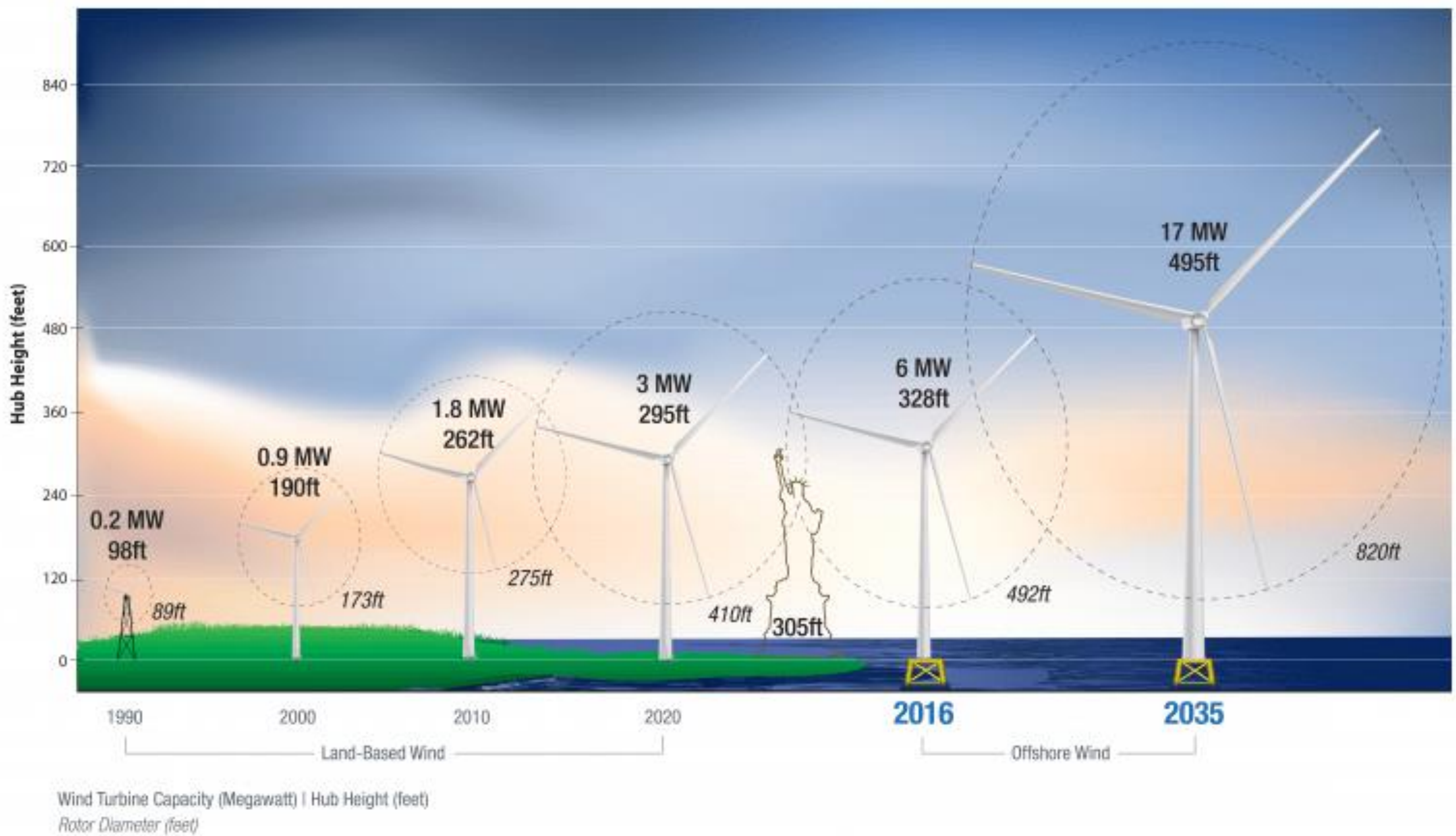
Steel protection

- Mild steel has been used for more than 100 years and we have good knowledge on corrosion processes
- The object is normally a fixed installation

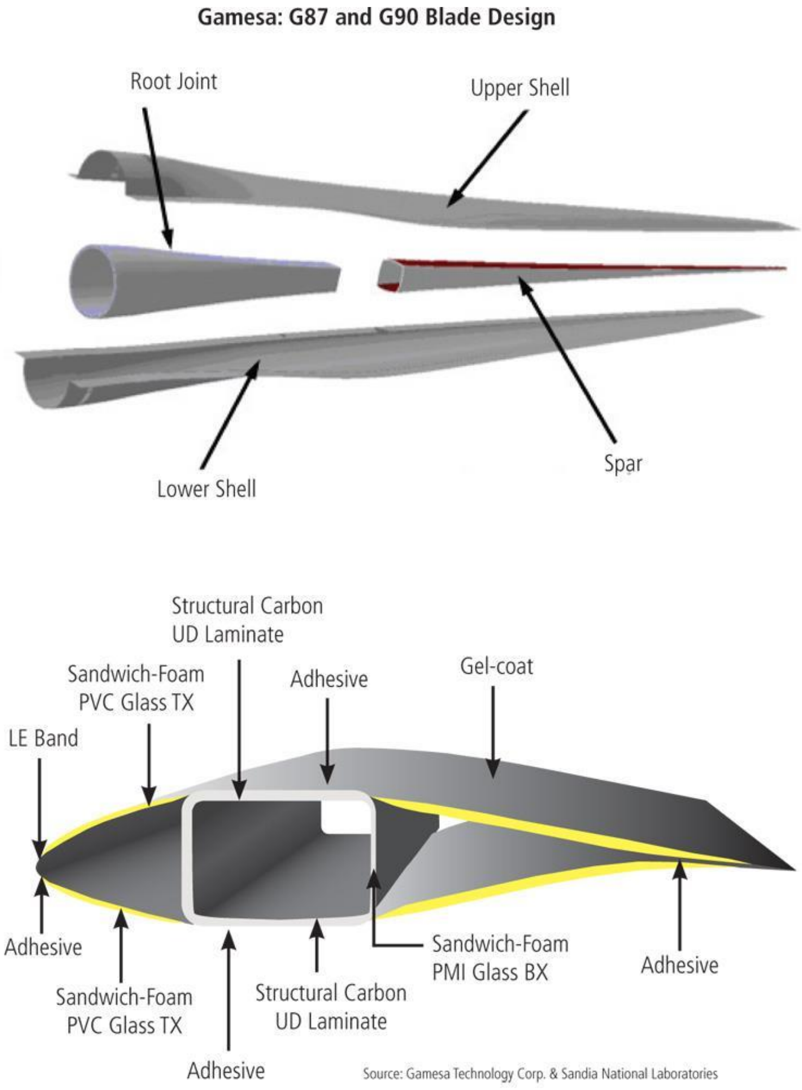
Blade protection

- Wind turbine blades has been made in commercial scale since early 1990’s
- Building material and design for blades are still in development (Trade Secrets)
- The object in moving at high speed during under changing weather conditions

Development in wind turbine size



How are blades made?
The glued blades – “bits and pieces”



The “One Shot Method”

Resins for blade manufacturing

Epoxy

Polyester / Vinylester

Polyurethane

Thermoplastics for smaller blades

Coating systems

Excluding joints

System with gel coat

- **Gel coat (in-mould)**
  - Epoxy or polyester
  - Rolled or sprayed
- **Topcoat**
  - 2-K Polyurethane
  - Solvent borne
    - Sprayed
  - Water borne
    - Rolled
- **Leading Edge Protection**
  - Tape
  - Liquid
  - Shell

System **without** gel coat

- **Putty / fairing compounds**
  - Solvent free epoxy
  - Automated assisted application
- **Primer**
  - Solvent borne epoxy
- **Topcoat**
  - 2-K Polyurethane
  - Solvent borne
    - Sprayed
- **Leading Edge Protection**
  - Tape
  - Liquid
  - Shell

Windmastic Coating Systems

System with gel coat

- **Gel coat (in-mould)**
  - Epoxy or polyester
  - Rolled or sprayed
- **Topcoat**
  - 2-K Polyurethanes
  - Windmastic Topcoat HS 200
    - Solvent borne, sprayed
  - Windmastic Topcoat AQ 2
    - Water borne, sprayed
- **Leading Edge Protection**
  - Tape
  - Liquid – Windmastic LEP Liq-2
  - Soft-shell

System without gel coat

- **Putty / fairing compounds**
  - Windmastic Putty EP-1
    - Epoxy, solvent free
- **Primer**
  - Windmastic 400 FC Primer
    - Solvent borne, epoxy
- **PoreFiller**
  - Windmastic PoreFiller PU
    - Polyurethane, solvent free
- **Topcoat**
  - 2-K Polyurethanes
  - Windmastic Topcoat HSX
  - Windmastic Topcoat HS 250
- **Leading Edge Protection**
  - Tape
  - Liquid – Windmastic LEP Liq-2
  - Soft-shell

Qualification and standardisation

- Most blade manufacturer has their own coating specification and qualification processes
- Qualification of single products
- Qualification of coating systems
- Specifications gives normally references to standard test methods known in the coating industry
- Examples of performance requirements for a topcoat
  - Colour
  - Gloss
  - Opacity
  - Rain Erosion Resistance
  - Fatigue
  - Adhesion

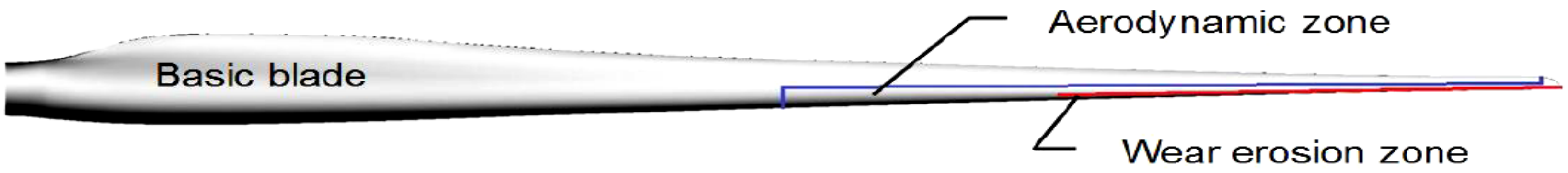
ISO 19392
Coating systems for wind-turbine rotorblades

- ISO 19392 can be been seen as a guideline for blade coating but is normally not used by the blade manufacturer in full extent.
  - Part 1 - Part 1: Minimum requirements and weathering
  - Part 2 - Determination and evaluation of resistance to rain erosion
  - using rotating arm
  - Part 3 - Determination and evaluation of resistance to rain erosion using water jet
  - Part 4 – Influence of rain erosion damage on the ice formation on rotor blades (draft)
  - Part 5 – Measurement of transmittance properties of UV protective coating (draft)
  - Part 6 – Determination and evaluation of ice adhesion (draft)
  - Part 7 – Determination and evaluation of resistance to hail (proposal)
  - Part 8 - Determination and evaluation of resistance to soiling (proposal)

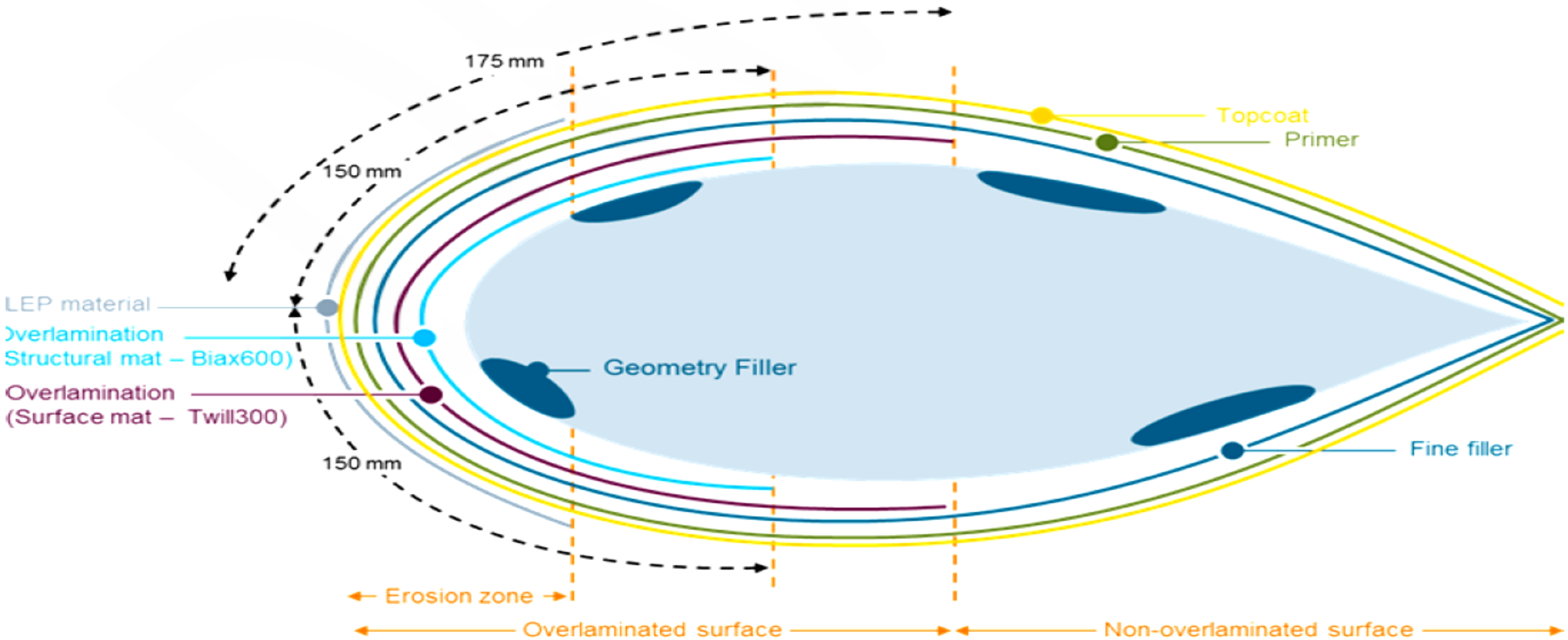
- Why do we not find the references to the standards in blade manufacturer specifications?
- Possible point of views seen from the blade manufacturers
  - Blade manufacturing is "industrial secrets" – both material used and processes
  - Competition
  - Requirements not relevant?
  - Standard takes long time to implement and be not match the manufacturer experince

CARBOLINE RAIN EROSION TESTING (RET)
LEADING EDGE PROTECTION (LEP)

EROSION OF A WIND TURBINE BLADE



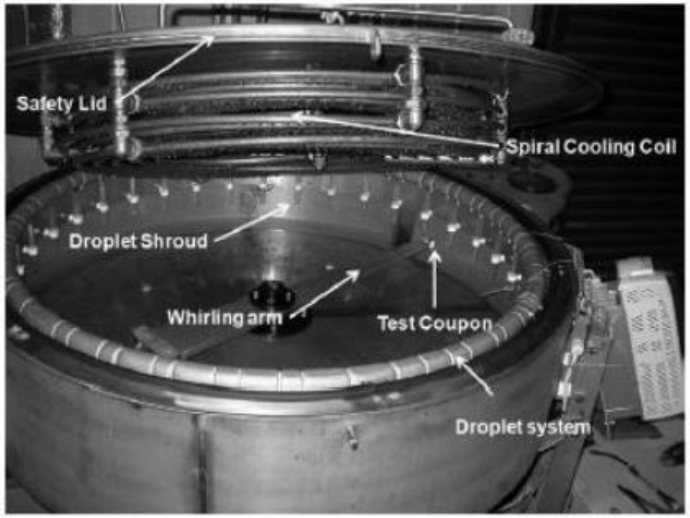
75 meter blade



Test of materials
Rain Erosion Testing

- Testing of materials for resistance of liquid impact started already in the 1920's
- The first "commercial" rotating arm test rig came into operation in the 1950's (UDRI – University of Dayton, USA) and was used for testing helicopter rotor blades
- Several test rigs has been operation since 1970. Most known are Saab, Polytech, Uni Limerick, Uni Strathclyde, Fraunhofer IWES

- Need for standardisation:
- 15 test rigs of R&D design in operating world- wide
- DNVGL-RP-071 testing of rotor blade erosion protection gives thoroughly method on how to interpret the test results

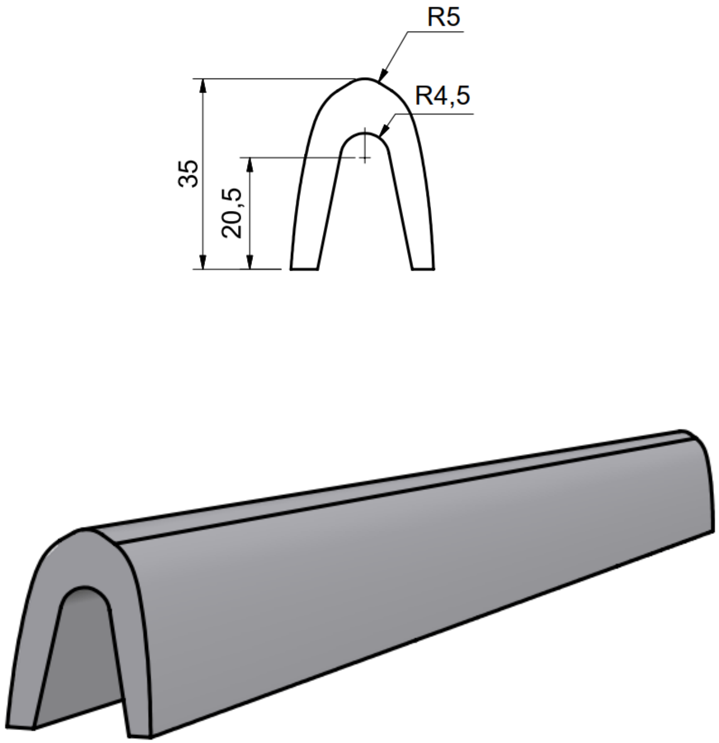


RET Container Solution

R&D / CARBOLINE
RAIN EROSION TEST RIG

Test specimen for RET testing

- Glass fibre reinforced epoxy specimen with a coating system. Length 40 cm
- Defined aluminium alloy specimen for calibration



Testing Conditions

References

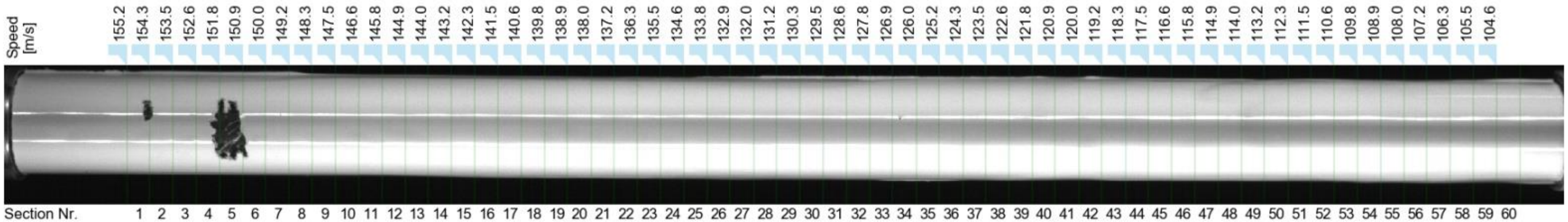
- DNVGL-RP 0171
  - Testing rotor blade erosion systems
- ISO 19393-2
  - Determination and evaluation of resistance to rain erosion
- ASTM G73-10
  - Liquid impingement erosion using rotating apparatus

- **Testing condition**
  - Maximum speed
    - Tip 156.6 m/s
    - Center 130 m/s
    - Root: 105.5 m/s
- Droplet size 2.5 mm
  - Alternative drop size posible
- Water flow 60 liter / hour
- Temperature 8 °C
- Specimen length 40 cm
- Photo documentation

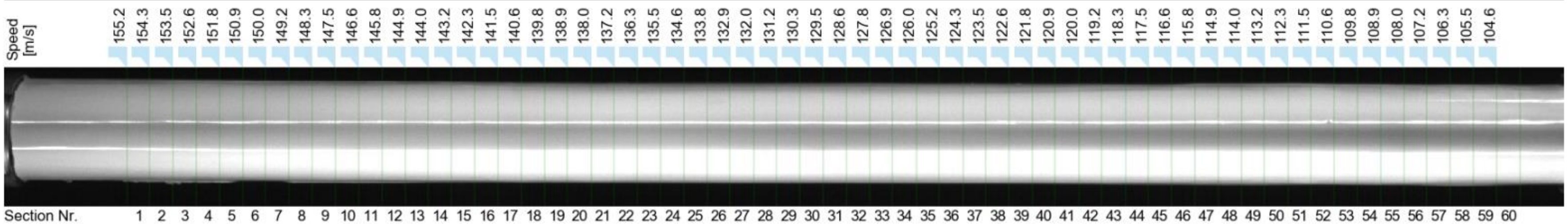
Test results from Rain Erosion Testing

Slice Number	Slice Group	Slice Duration	Accumulated Erosion Time
9	9	30:00	02:30:00

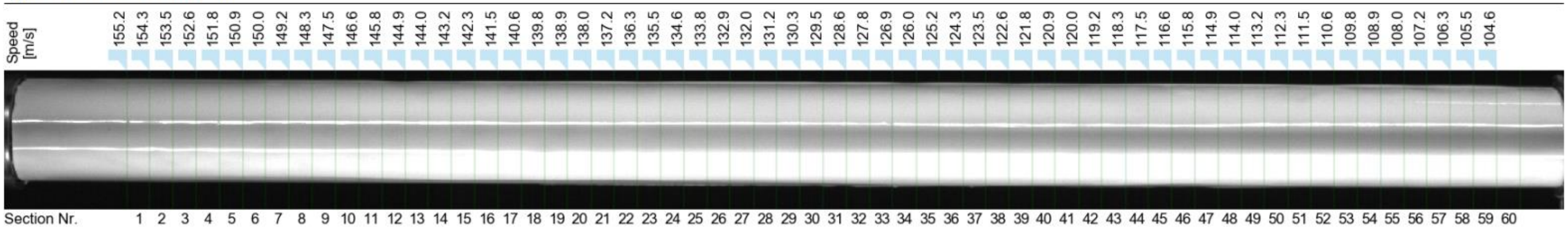
Specimen ID: 1922-05 3-1



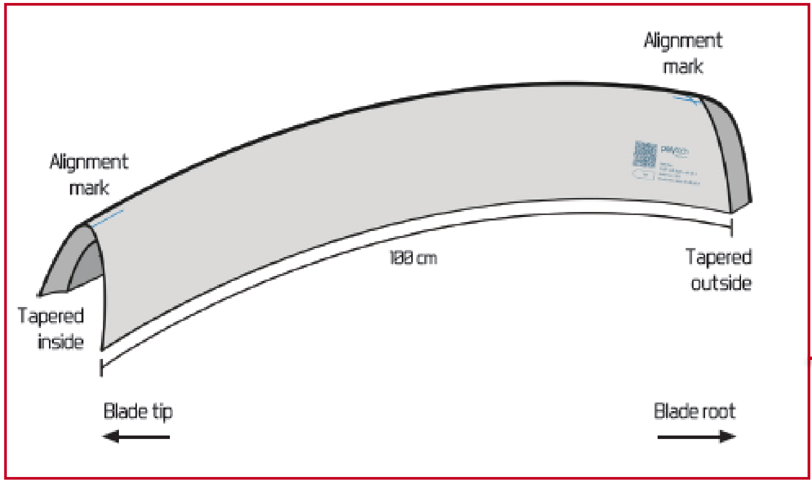
Specimen ID: 1922-05 3-2



Specimen ID: 1922-05 3-3



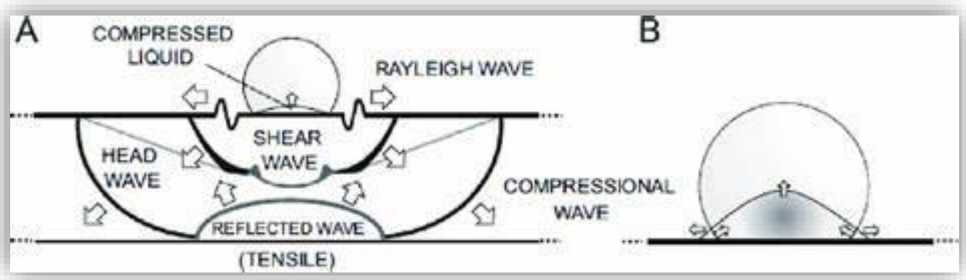
Leading Edge Protection



- LEP is necessary to protect the blade from erosion of rain, hail or sand on the edge area. The erosion increase with the blade length

  Main products
- **Tape** – normally transparent thick film from 3M
- **Liquid** solvent free polyurethane or polyurea supplied in 2K cartridges. The coating suppliers choice
- **Soft / flexible shell** glued to the leading edge – for offshore blades

Water droplet impact



Polymers with high tensile strength and flexibility will ideally protect the blades against rain erosion. They are able to absorb and distribute energy. Adhesion to the surface (coating) is of high importance.

Rain Erosion Test (RET) – which data do we get?

- RET is mainly used for giving information on erosion resistance of topcoat or LEP but do also gives us additional data on adhesion. Photo documentation available during testing.

- Typical system for test (development phase)
- Primer (Gel coat) / Topcoat
- Primer (Gel coat / Topcoat / LEP)
  - Intercoat adhesion
  - Adhesion LEP to topcoat

- Full system testing including putties
  - Intercoat adhesion
  - Porosity and fatigue of putties and the influence of erosion of topcoat and / or LEP

Liquid LEP

- Two component fast curing solvent free flexible polyurethan normally supplied in cartridges for manual application. Can be used in shop or site applied.

- Technology
  - Polyurethane
  - Polyaspartic
  - Polyurea

- Key characteristics
  - Flexible – to absorb energy

- Drawbacks:
  - Flexible – what about robustness?
  - Short port life – “slow” curing?
  - Manual application – how to apply a uniform film without pores?

- Performance – can we related testing to real operating conditions?

- Main challenge – to transform physical research on liquid impact (academia) into user-friendly, reliable products (industry)

Liquid LEP – what are the industry doing?

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- Improvement can only be done when partners work together
- Who are the partners?
  - Raw material supplier
  - Coating manufacturer
  - Testing institutes
  - Academica and research institutes
  - Blade manufacturer
  - End used / wind turbine owners

- Good initiatives
  - IEA (International Energy Agency) Wind Task 46
  - DTU (Danish Technical University) – Yearly Leading Edge Symposium (February)

Rain Erosion Testing – what more do we need?

Rain Erosion Test – as it says – gives us data on erosion resistance and durability.

What about other natural impacts that degrade the coating of the blades?

How to test these, separate or in combination?

Test methods exists
ISO 19392-series

ISO 12944-6 Cyclic Testing
Environment impact on rain erosion resistance

ISO 12944-9:2018(E)

Annex B
(normative)

Cyclic ageing test

The exposure cycle used in this procedure lasts a full week (168 h) and includes:

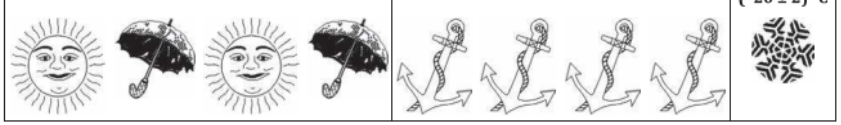
a) 72 h of exposure to UV and condensation in accordance with ISO 16474-3 under the following conditions:

— method A, cycle 1 of ISO 16474-3 alternating periods of 4 h exposure to UVA-340 lamps at (60 ± 3) °C and 4 h exposure to condensation at (50 ± 3) °C,

b) 72 h of exposure to neutral salt spray in accordance with ISO 9227;

c) 24 h of exposure to low temperature at (−20 ± 2) °C.

Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
UV/condensation — ISO 16474-3			Neutral salt spray — ISO 9227			Low-temp. exposure at (−20 ± 2) °C



Start the UV/condensation period with UV exposure and finish with condensation.

Between the salt spray and low-temperature periods, rinse the panels with de-ionized water but do not dry them.

At the beginning of the low-temperature period, the panel shall reach the temperature of (−20 ± 2) °C within 30 min.

Expose the test panels for 25 cycles or 4 200 h.

- Testing of rain erosion before and after cyclic test
- Challenges
  - Duration (6 months)
  - Size of test specimen
  - Should be combined with flat panels (laminates) for additional evaluation.
  - Adhesion, colour, gloss

Summary

- Wind turbines and blade manufacturing is a relatively young industry with most of the technology developed the last 30 years
- The blades has been in constant development when it comes to processes, materials, size and exposure (stain)
- The industry partly use testing standard taken from other industries
- Testing requirements and methods have been developed alongside an industrial evolution
- Products can be tested as single products or in systems. The final system testing (process compatibility) is normally done by the blade manufacturer
- Qualification by the manufacturer can take 9 – 24 months including test application on a full set of blades
- Development in blade size: longer and lighter blades gives more movement of the blade during operation; giving stress and fatigue that can make the coating to crack