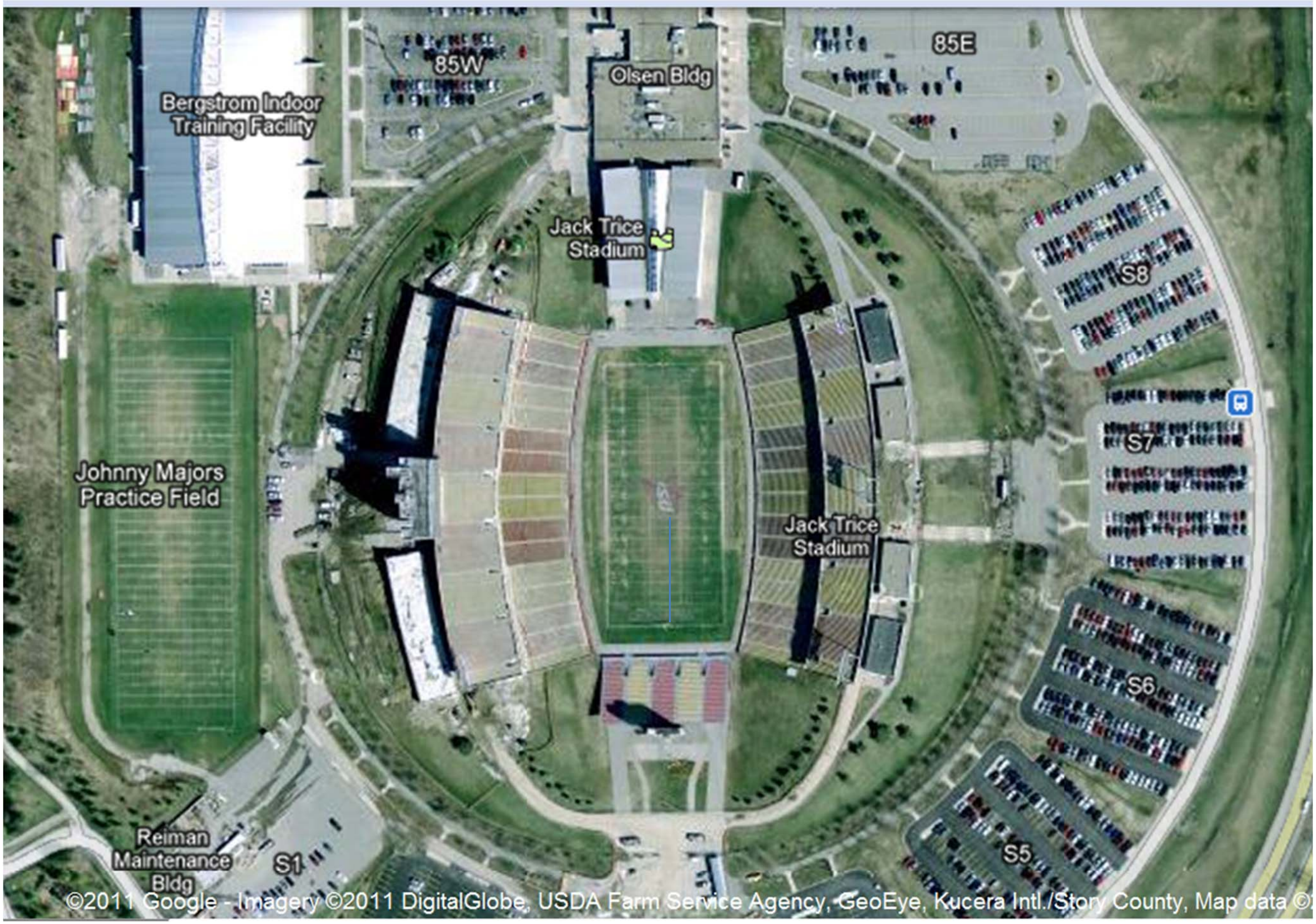

85W
Olsen Bldg
85E
Bergstrom Indoor Training Facility
Jack Trice Stadium
S8
S7
Johnny Majors Practice Field
Jack Trice Stadium
S6
S5
Reiman Maintenance Bldg
S1
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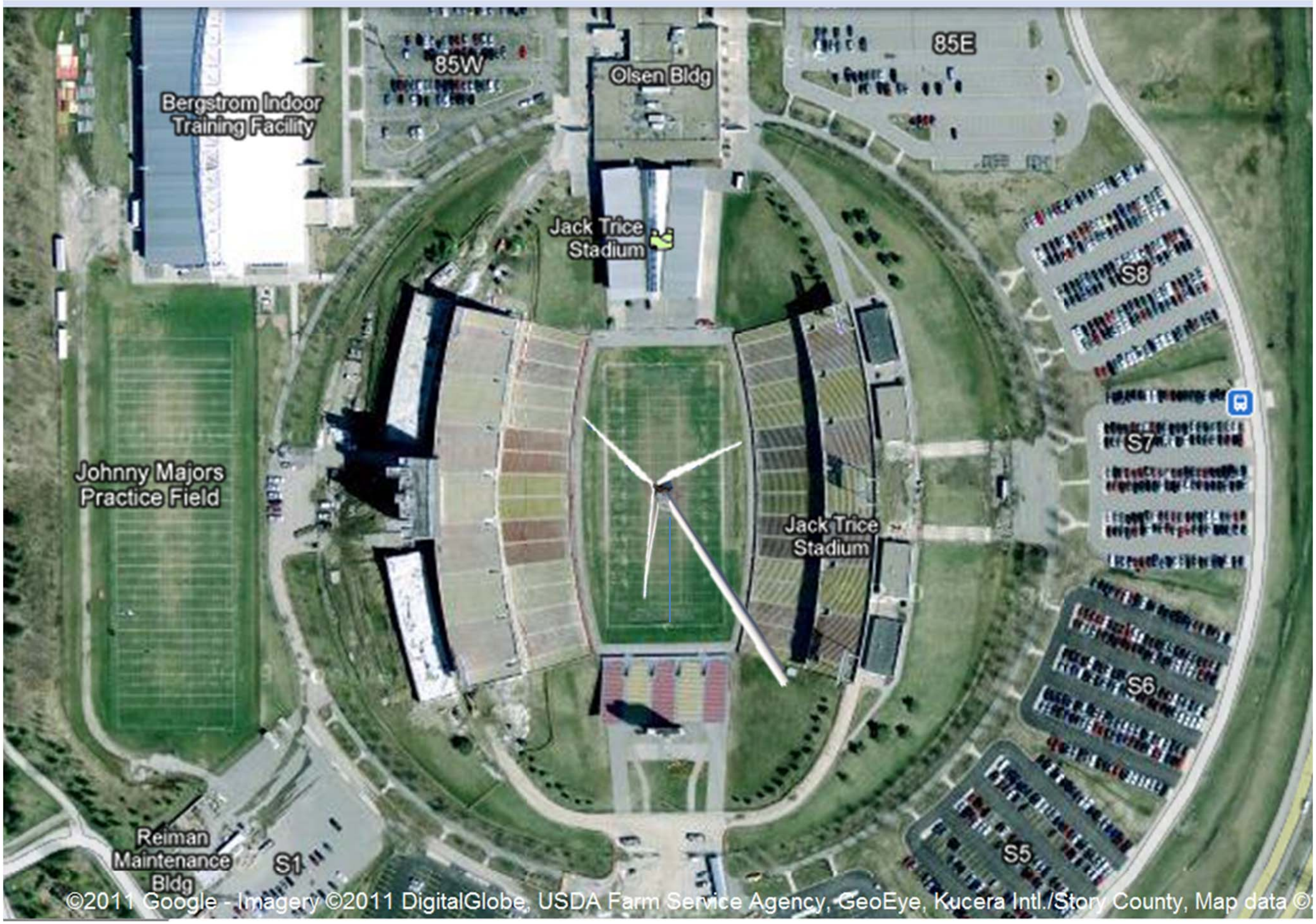

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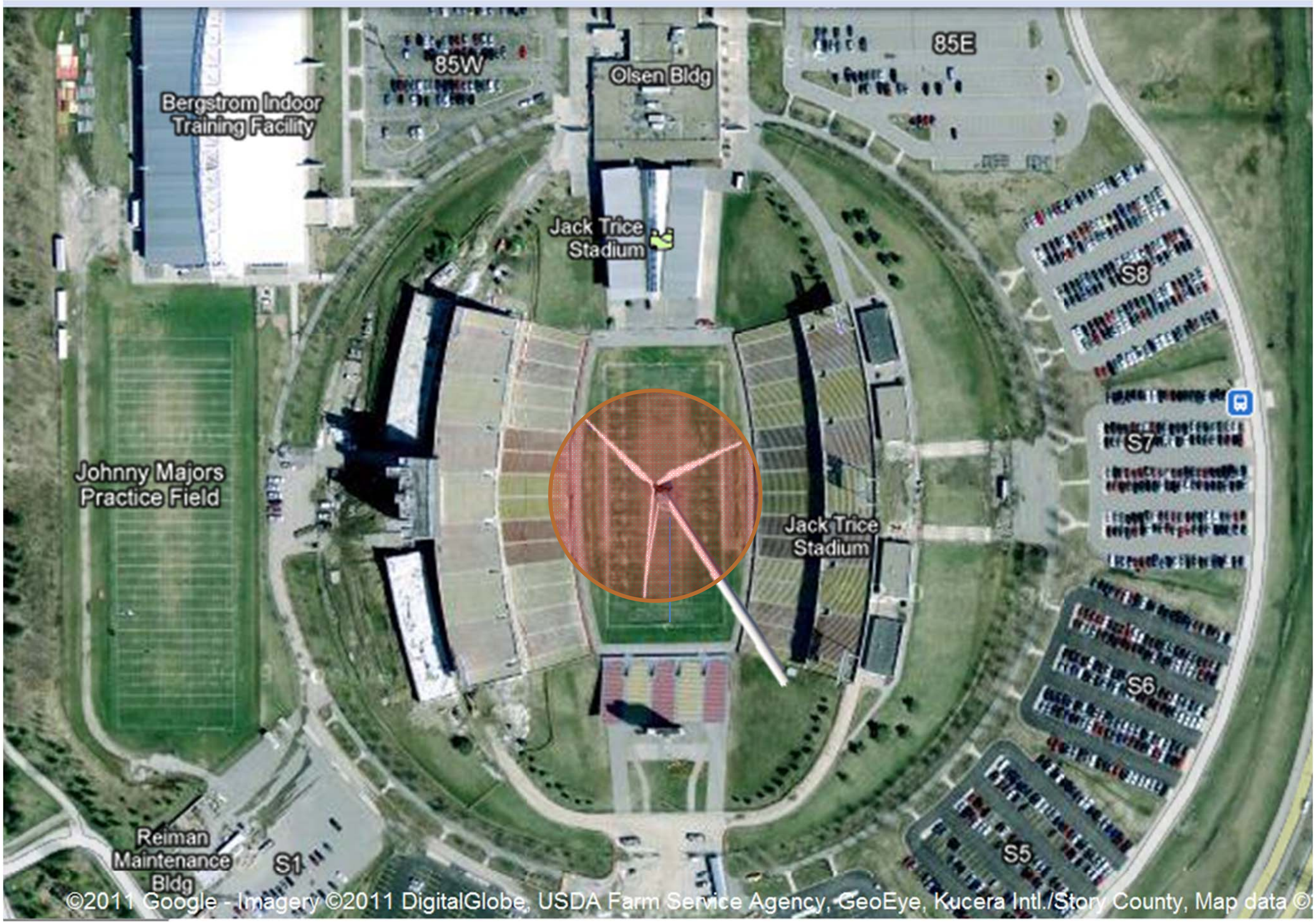
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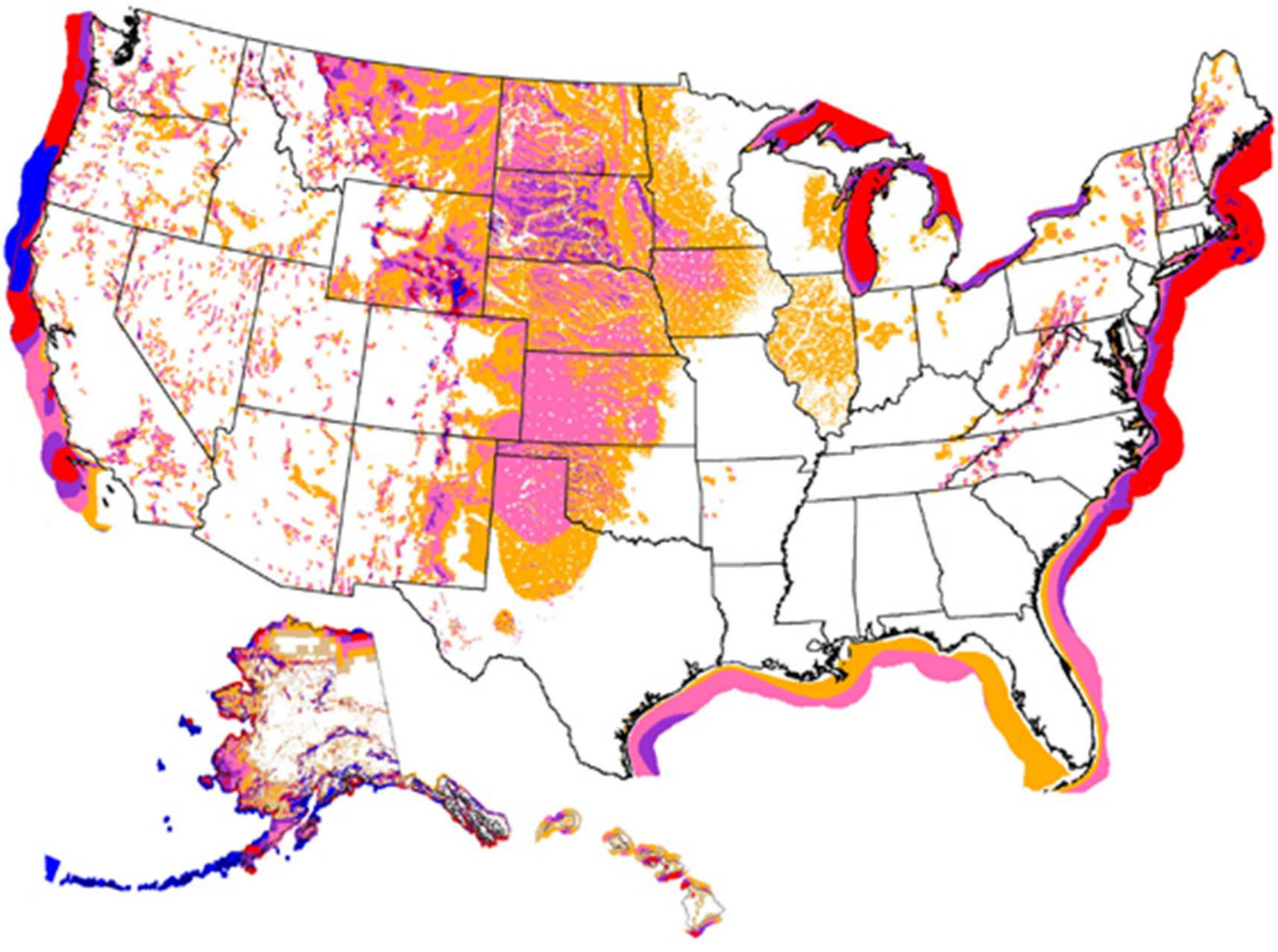
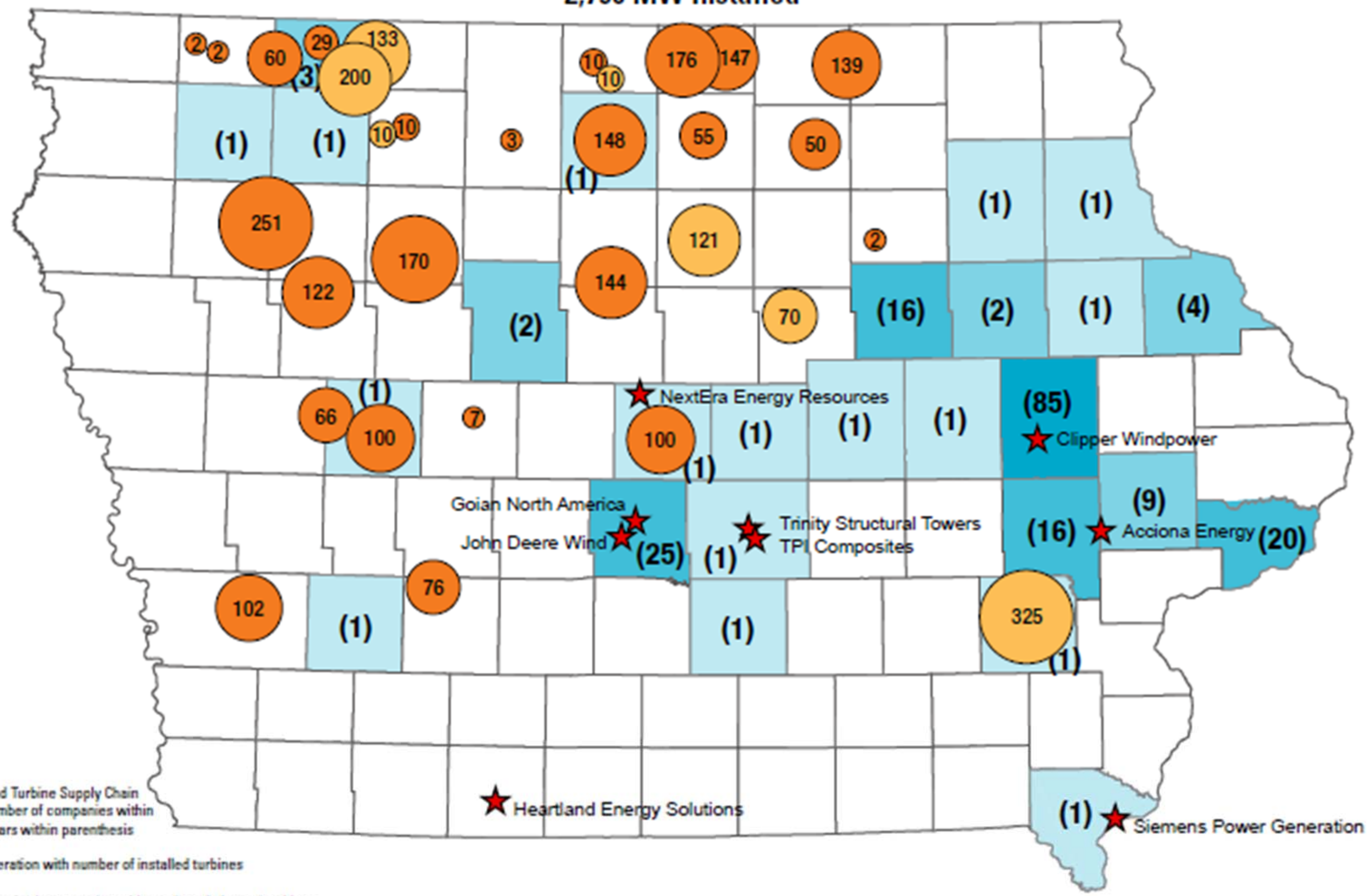


WIND TURBINE MANUFACTURING, SUPPLIERS, FINANCING AND FARMS IN IOWA

2,790 MW Installed



LEGEND

- County with Wind Turbine Supply Chain Operations - Number of companies within the county appears within parenthesis
- Wind farm in operation with number of installed turbines
- Wind farm in planning/construction with number of planned turbines
- Wind Manufacturing and Financing companies

Source: American Wind Energy Association, U.S. Wind Energy Projects - www.awea.org (4/23/09) additionally, some data is gathered from recent news articles and announcements of planned sites.
This map is only a representation of the wind farms and does not reflect actual land area utilized by wind farms.

Iowa Department of Economic Development
200 East Grand Avenue
Des Moines, Iowa 50309 U.S.A.
Domestic: 1.800.245.4692 International:+1.515.242.4896

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Component Cost

Table 6.2 Percentage Contribution of Different Components to Machine Cost from Table 6.1, Classified According to the Power Law Assumed to Define the Relationship Between the Component Mass and the Machine Rated Wind Speed

Components for which the weight/cost is independent of rated wind speed		Components for which the weight varies as rated wind speed		Components for which the weight varies as rated wind speed squared		Components for which the weight varies as rated wind speed cubed	
Component	Cost	Component	Cost	Component	Cost	Component	Cost
Foundation	4.2%	Blades	18.3%	Gearbox	12.5%	Generator	7.5%
Controller	4.2%	Hub	2.5%	Brake system	1.7%	Grid connection	8.3%
Assembly	2.1%	Main shaft	4.2%				
Transport	2.0%	Nacelle	10.8%				
		Yaw system	4.2%				
		Tower	17.5%				
Total	12.5%	Total	57.5%	Total	14.2%	Total	15.8%

Wind Energy Handbook

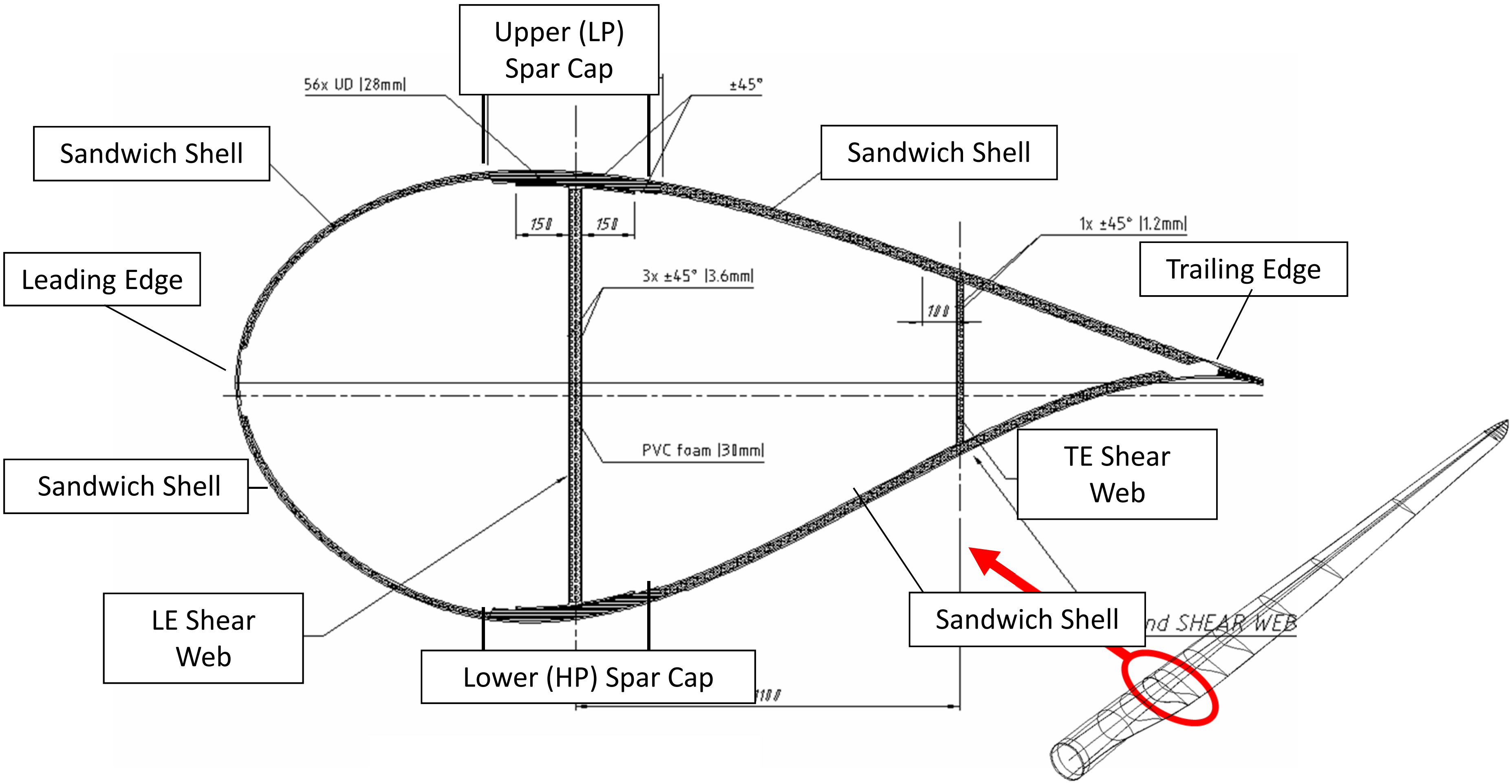
Wind Energy Manufacturing Challenges

- Size
- Volatile demand
- Cost constraints

Travel Restrictions

- Road:
  - Standard
    - 4.1 m high by 2.6 m wide
    - Net weight 21 tons
  - Very Expensive
    - > 4.83 m high
- Rail:
  - 3.4 m width
  - 4.0 m height

Blade with Shear Web bonded to Spar Cap



Courtesy: Nolet, TPI

Blade with Box Structure

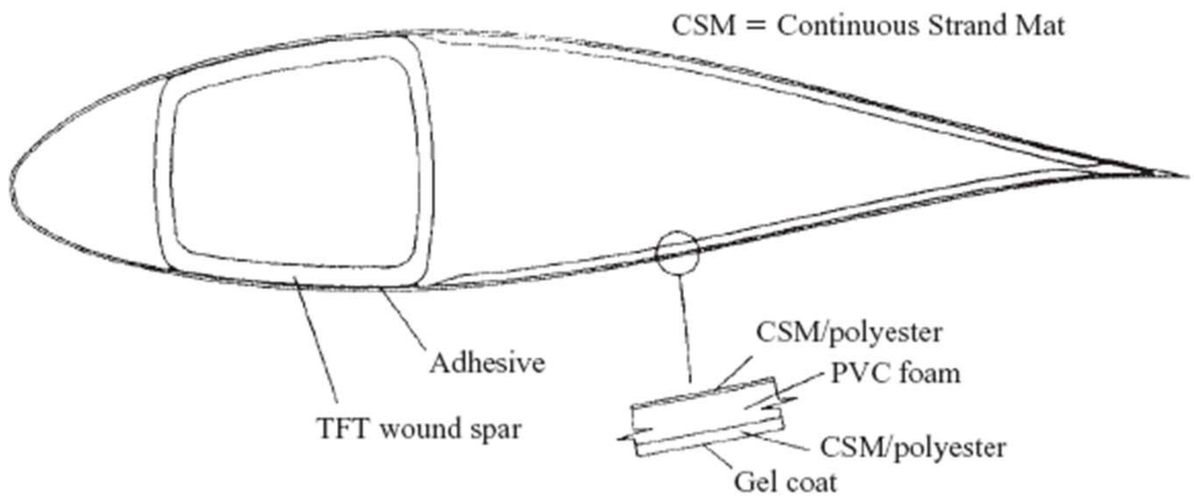


Figure 7.4 Glass-fibre Blade Construction Using Compact Spar Wound with Transverse Filament Tape (TFT) on Mandrel. (Reproduced from Corbet (1991), by permission of the DT1 Renewable Energy R&D Programme)

Power, Length and Weight

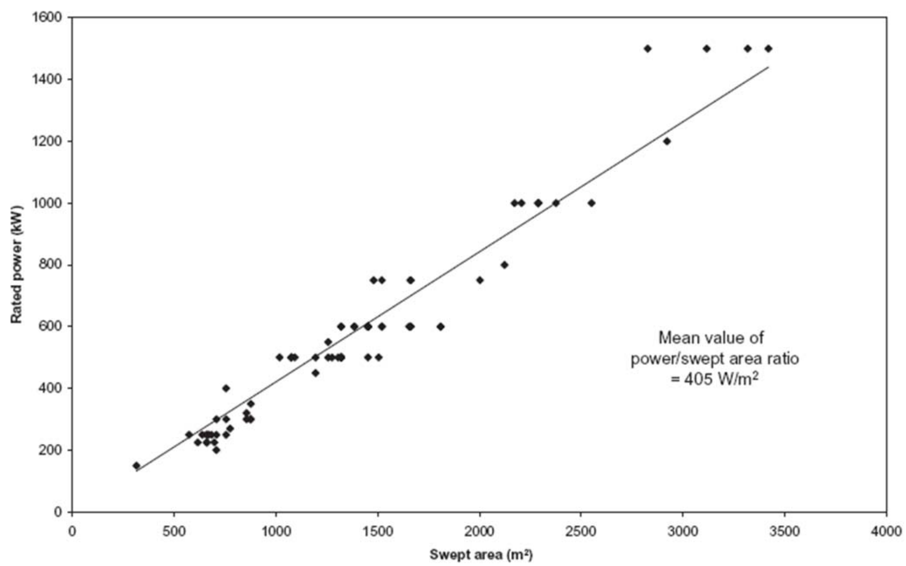
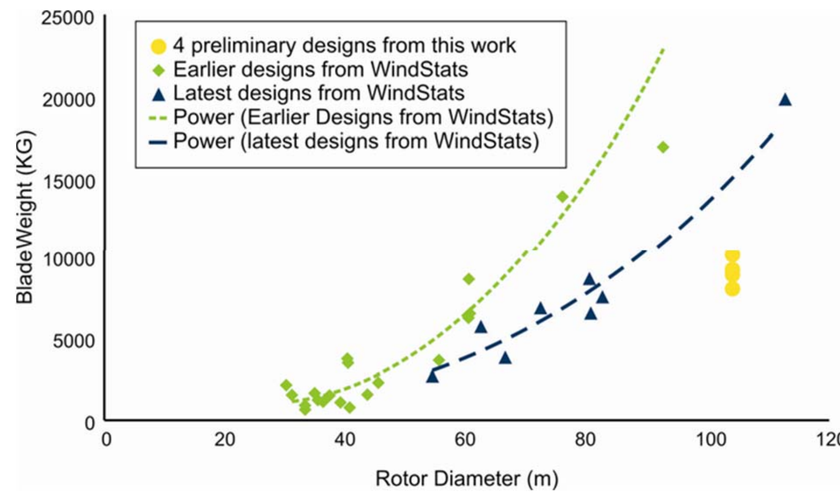


Figure 6.3 Rated Power *versus* Swept Area for Turbines in Production in 1997



Open Mold Composite Process

- Hand lay up
  - Fibers placed in mold:
    - Dry fibers placed and then matrix added
      - Pour or brush or spray >> rolled to achieve mixture
      - Vacuum used to ‘pull’ matrix into fiber
    - Prepeg placed in mold
- Automated tape laying machine
  - Requires use of prepeg
  - CNC control

Image sources: http://www.bauteck.com/manufacture/Manufacture2.htm 4/5/9
http://www.mmsonline.com/articles/getting-to-know-black-aluminum.aspx 4/5/9

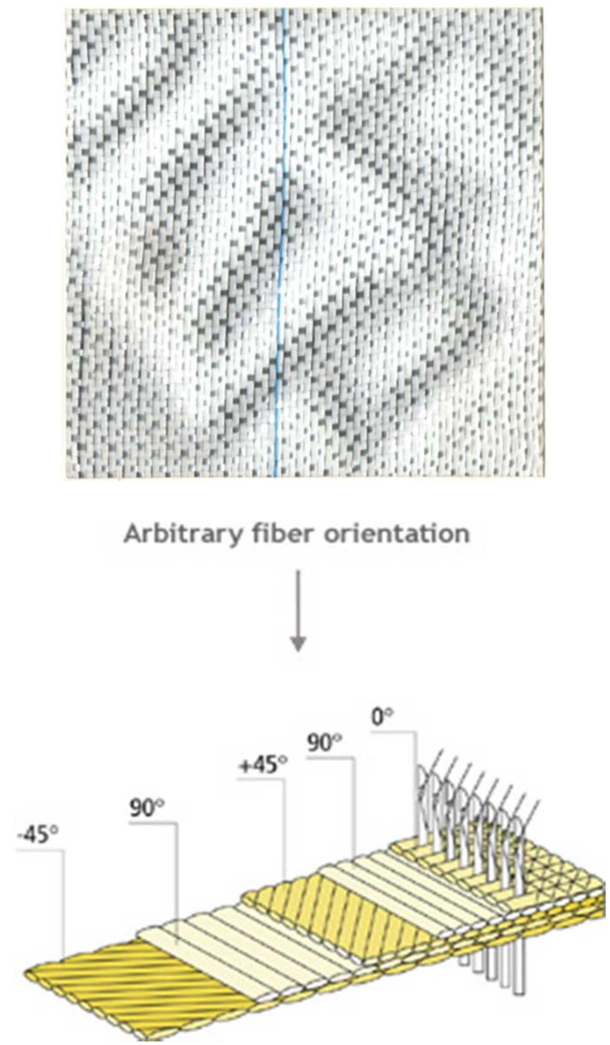
Reusable Silicon Bag Technology for SCRIMP®

o Silicone bags are rapidly fitted to the infusion tool
o Feed lines, vacuum lines and embossed distribution channels are integrated into the bag improving the repeatability of the process (TPI Patented Technology)

Courtesy: Nolet, TPI

Fibers

- Woven Fabrics
  - Higher cost, less applicable as structural components for blades
- Non-woven Multiaxials
  - Most widely used in VARTM processes
  - Low-cost, non-crimp form results in superior performance
  - "Uni-directional", Biaxial, Double Bias, Triaxial and Quadraxial material forms available.



Courtesy of Saertex USA

Courtesy: Nolet, TPI

Blade Materials

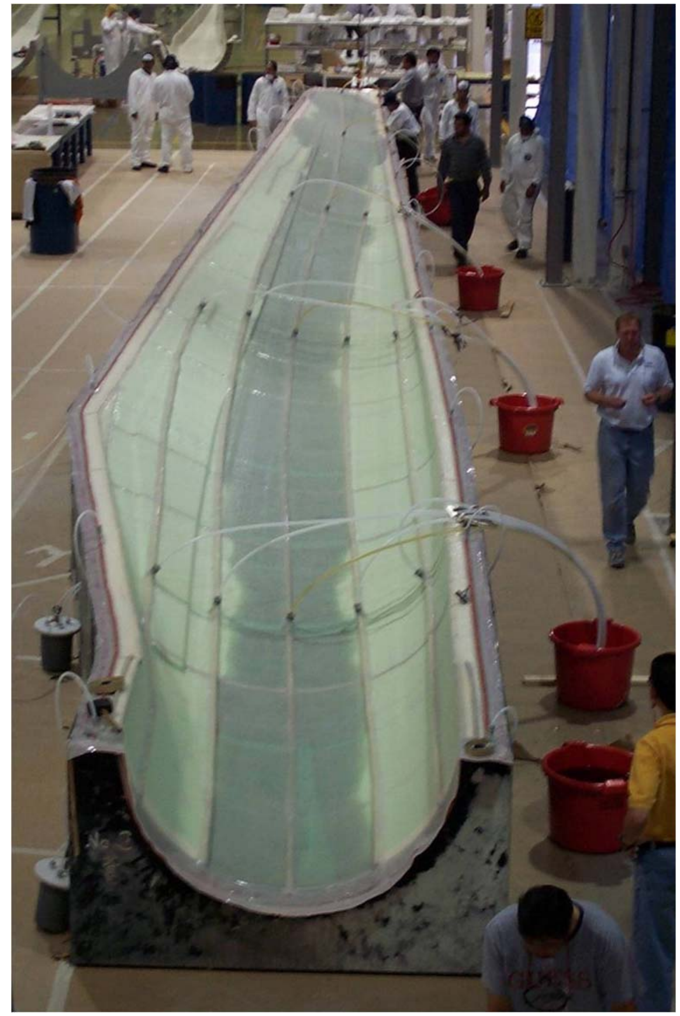
	UTS	UCS	UCS/sg	Fatique % of UCS	Stiffness/sg	E/UCS^2
Glass/X	880	720	390	19	20	.07
Glass/polyester	700	580	310	21	18	.1
Carbon/epoxy	1830	1100	700	32	90	.12
Birch/epoxy	117	81	121	20	22	2.3

- compressive strength-to-weight ratio,
- fatigue strength as a percentage of compressive strength,
- stiffness-to-weight ratio,
- a panel stability parameter, E/(UCS)2.

Source: Wind Energy Handbook

Resin Matrices

- Epoxies remain a primary resin of use in European based blade designs
- Vinyl-esters are attracting much interest by blade designers
- Polyester resins are still prominent in the industry.
- Thermoplastics and other matrices



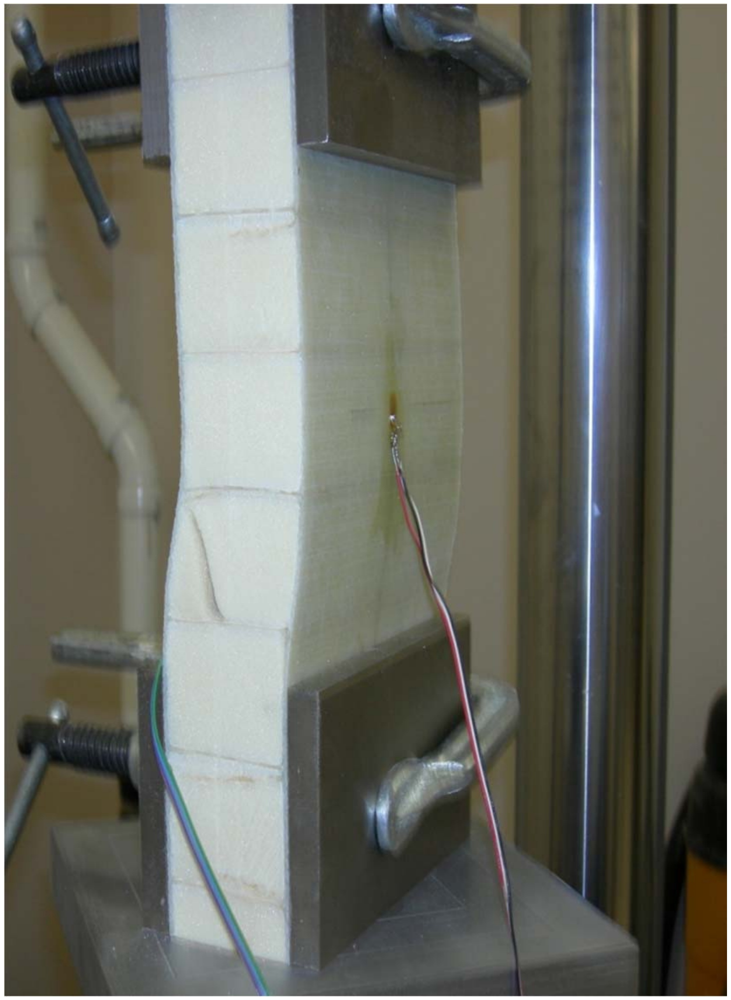
Courtesy: Nolet, TPI

Adhesives

- 2 Part Epoxy Paste Adhesives specifically formulated for their thixotropic properties are the mainstay for bonding and assembly
  - Costly, but result in very good mechanical properties when applied correctly
- Methyl-methacrylates provide excellent adhesion to polyester resin composites
  - Lower strength and stiffness
  - Greater fracture toughness
  - Extremely "tenacious" adhesion
  - Short cycle time potential

Courtesy: Nolet, TPI

Core Materials



- Used for stability in leading/trailing edge panels and shear webs.
  - End Grain Balsa
    - Low Cost, High Shear Properties, Higher Weight
  - Foam Cores
  - Engineered Core Materials

Courtesy: Nolet, TPI

Quality Systems/Engineering

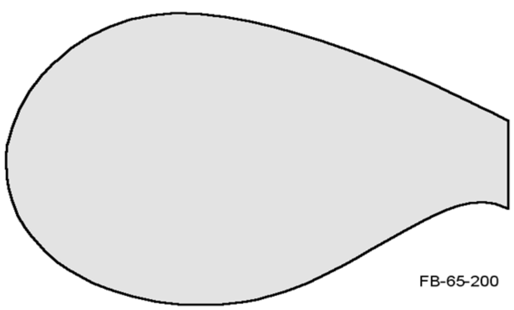
Full-Scale Blade Proof Testing:

- 46.2m Blade at 90% Max Operating load during proof testing at Vientek
- Tip deflections exceed 8 meters at max load.

Courtesy: Nolet, TPI

Options for Large(r) Blades

- Manufacturing
  - Make at point of use
  - Make in region of use
  - Import
- Design
  - Flatback design
  - Design in 2 pieces
  - Materials to reduce weight



Remote Blade Manufacturing Demonstration – Sandia 2003

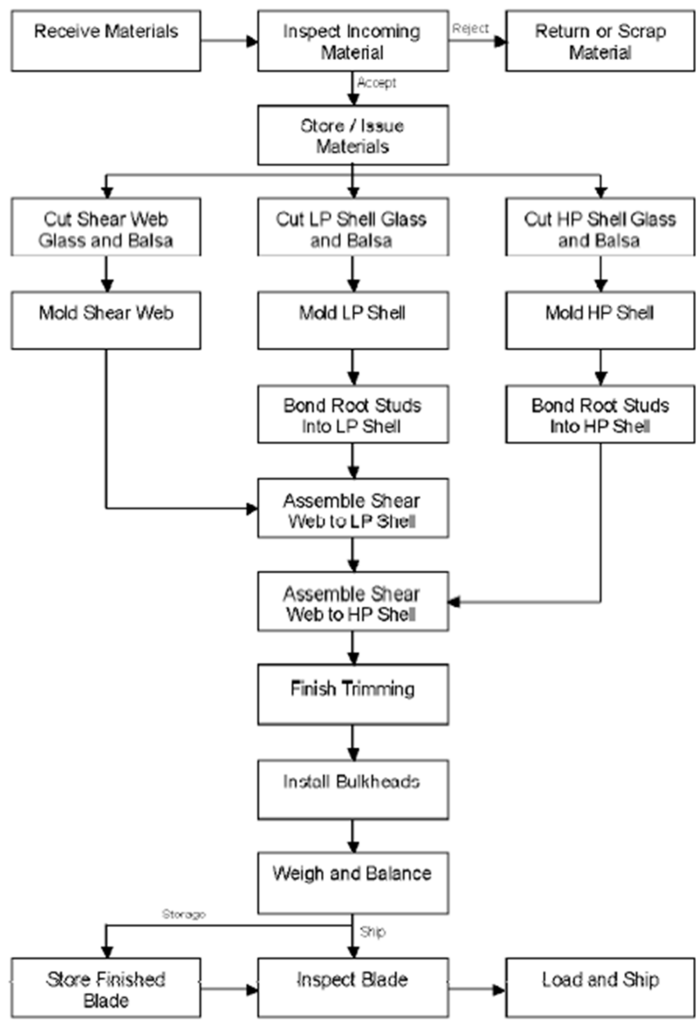
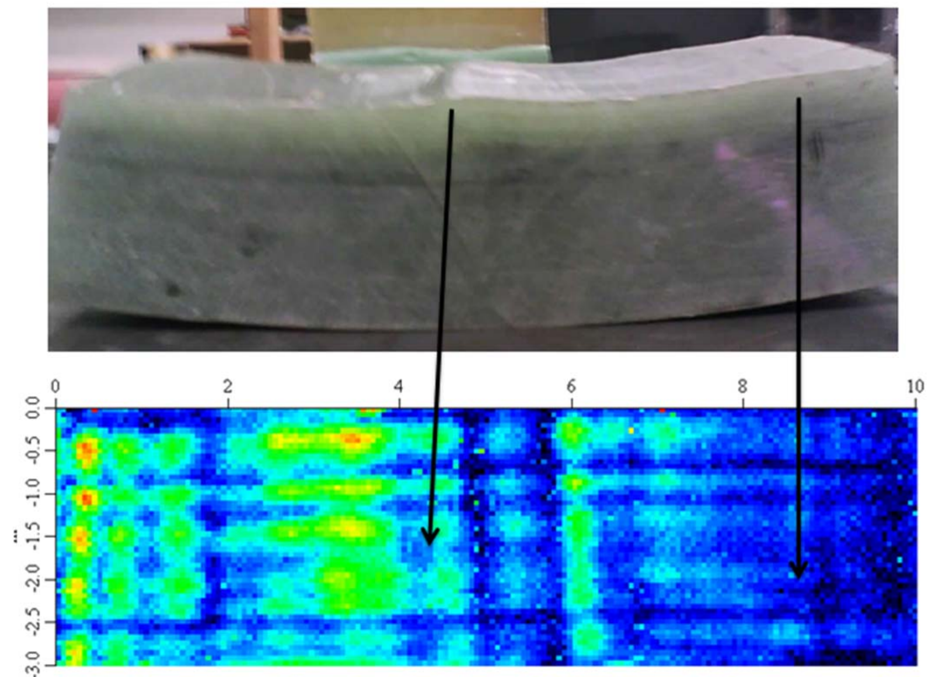


Figure 2.1 Blade Manufacturing Process Schematic

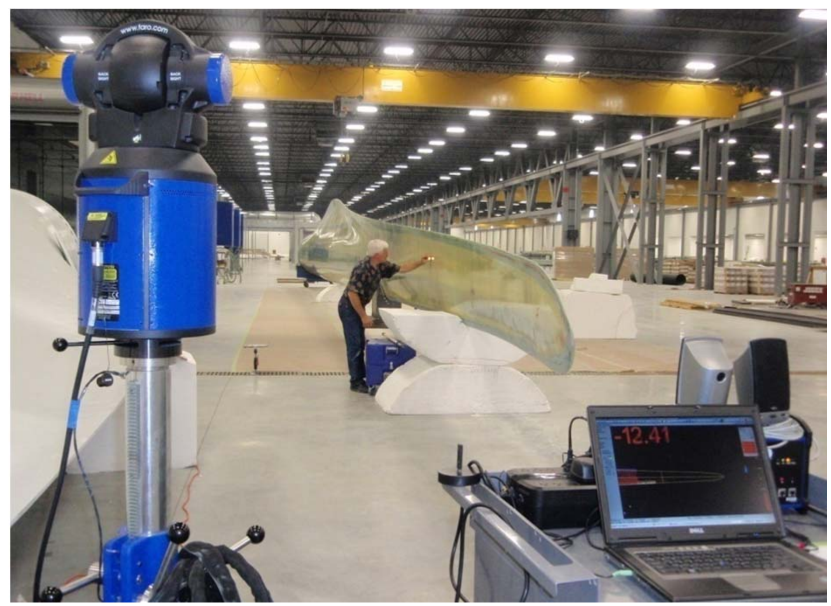
Sandia/ISU: NDE

- Evaluate NDE options
- Develop Ultrasonic Testing (UT) techniques
  – Bonds
  – Spar cap
  – Root sections



ISU: Assembly Variation

- Maintain +-mm across 50m assembly
- Joints are critical

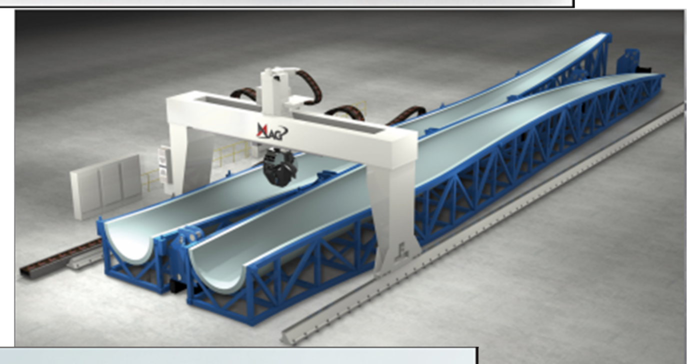


ISU Effort: Fabric Layup

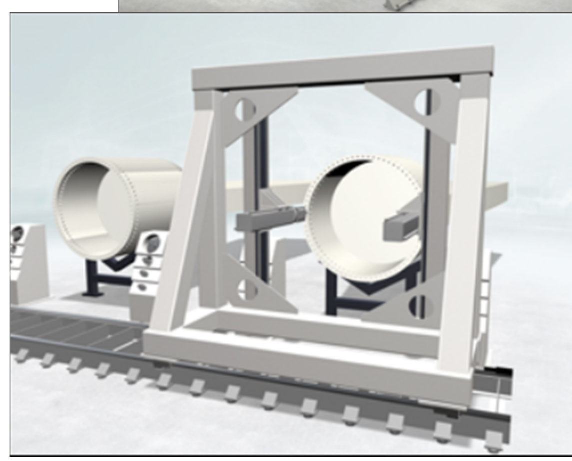
- 4m spar cap "mold"
  - Represents an extreme case of geometric shape change over a span, but similar
- Studying 2D fabric placement in 3D mold

Future Automation Systems?

Rapid Material Placement Systems (RMPS)
Automated blade molding



Automated root end machining for wind blades
Machine adapts automatically to blade position
Machining processes: Sawing, milling, boring and trimming

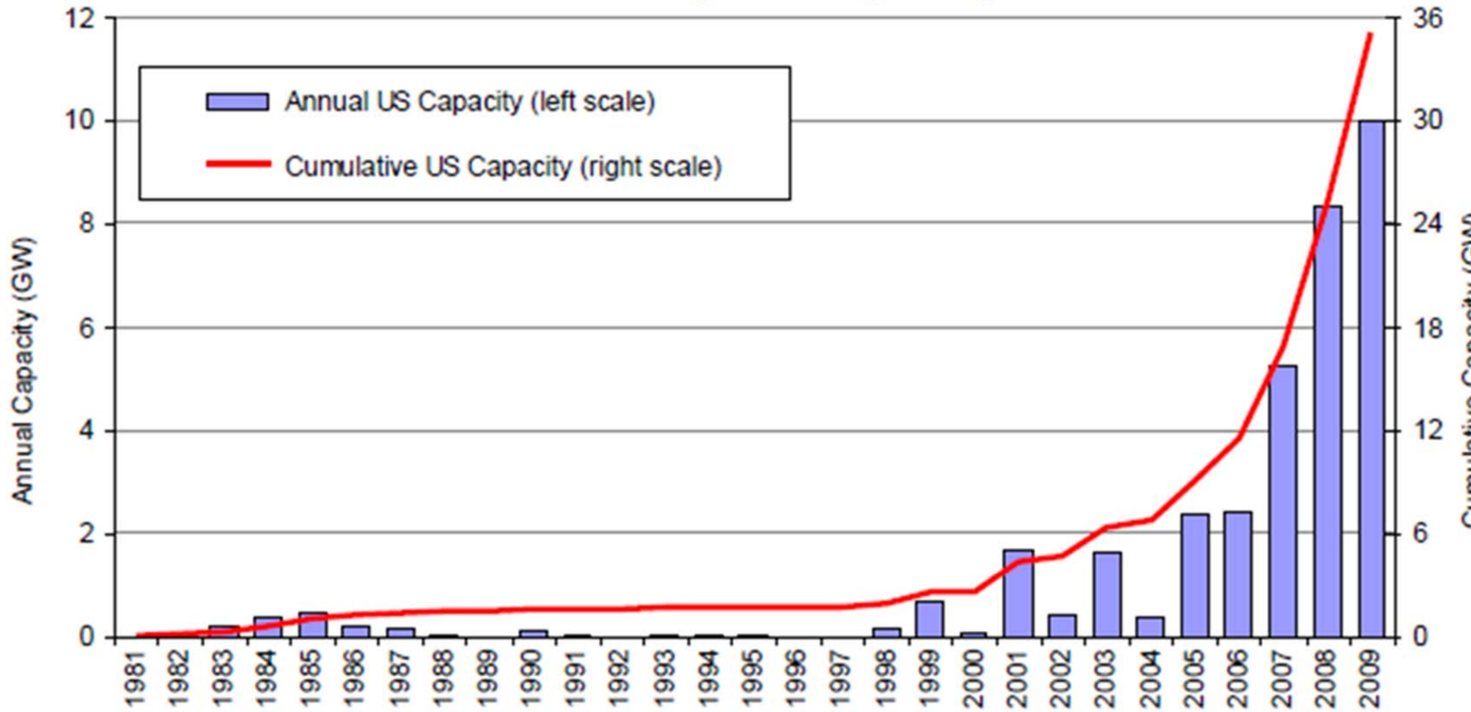


http://mag-ias.com/index.php?id=308&L=2

WIND AND WATER POWER PROGRAM

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

U.S. Wind Power Capacity Up >40% in 2009



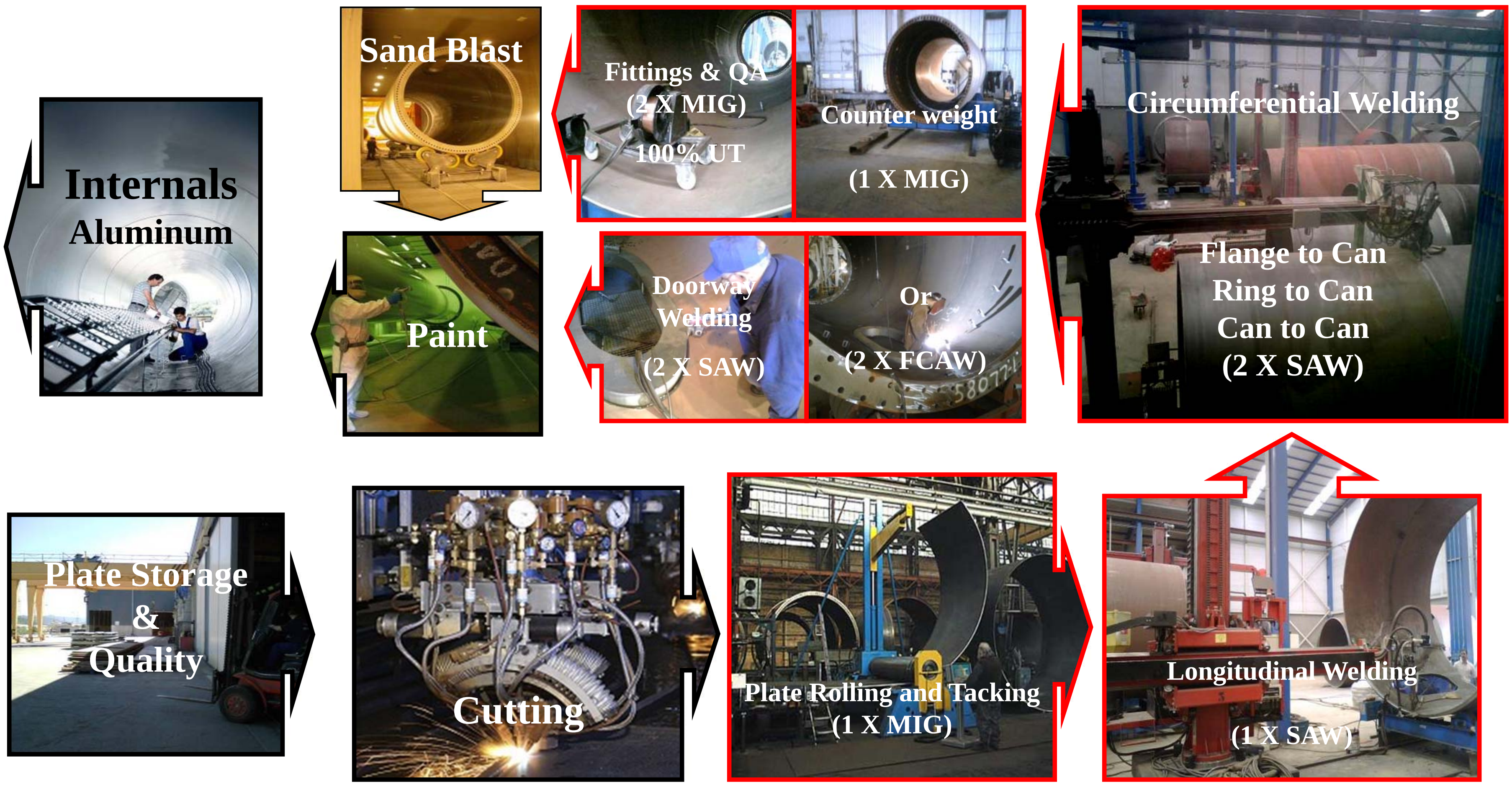
Record year for new U.S. wind power capacity:

- 10 GW of wind power added in 2009, bringing total to ~35 GW
- Nearly $21 billion in 2009 project investment

(from the Wiser and Bolinger report on wind in 2009)

Towers

Typical Wind Tower Plant



Courtesy: Lincoln Electric

Plate Rolling

http://www.directindustry.com/prod/davi-promau/sheet-metal-calendering-line-for-wind-tower-16273-367798.html

Longitudinal & Circumferential Welding

- Typically Tandem, triple Tandem or Twin Tandem systems, utilizing 2, 3 or 4 wires and welding heads.
- The Included Angle used on Bevels for Tandem Arc can be greatly decreased to 50º maximizing productivity and enabling single pass per side welding.

Courtesy: Lincoln Electric

Submerged Arc Welding

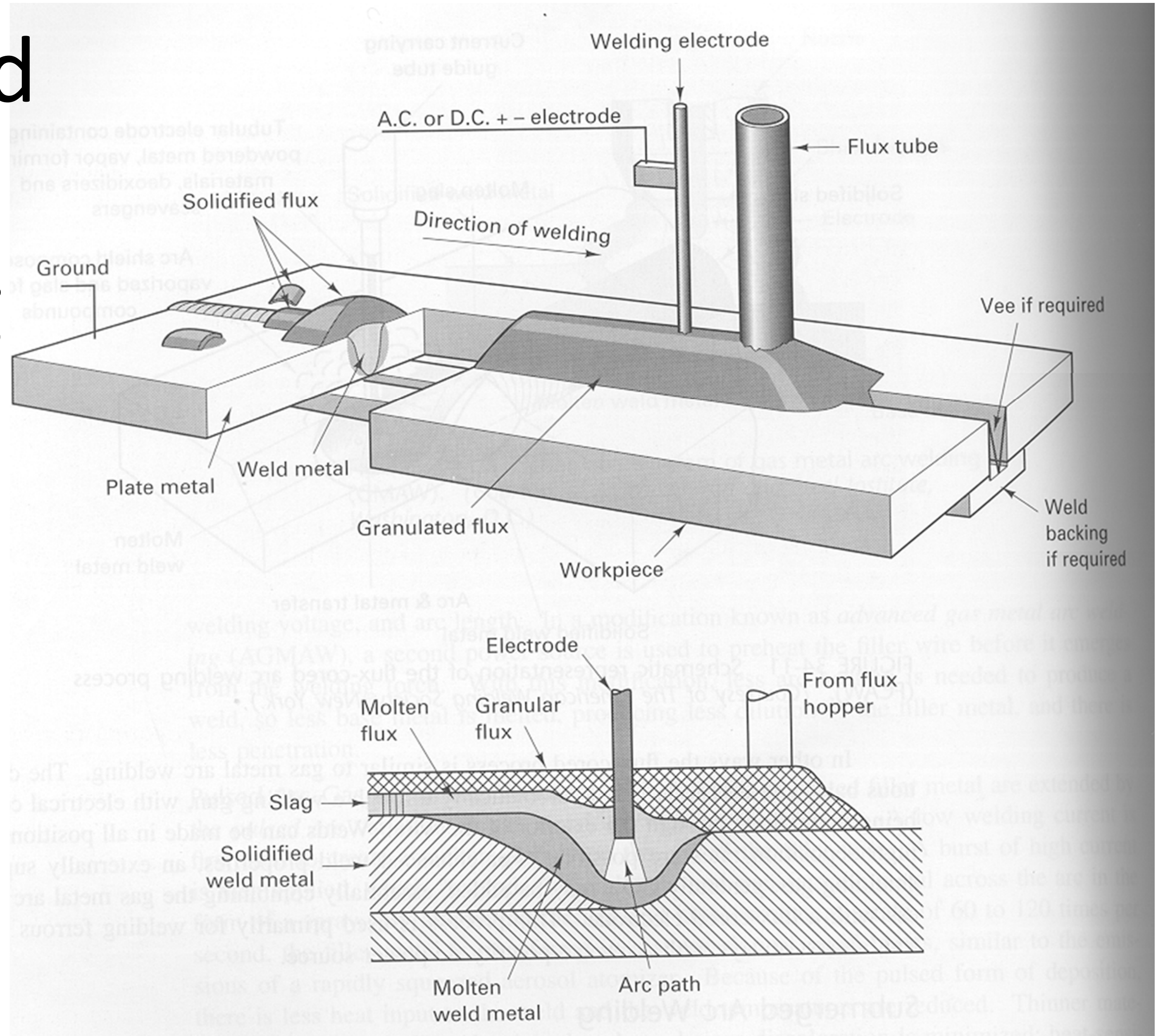


FIGURE 34-12 (*Top*) Basic features of the submerged arc welding process (SAW). *(Courtesy of Linde Division, Union Carbide Corporation.)* (*Bottom*) Cutaway schematic of submerged arc welding. *(Courtesy of American Iron and Steel Institute, Washington, D.C.)*

Example of a 4-wire SAW Procedure

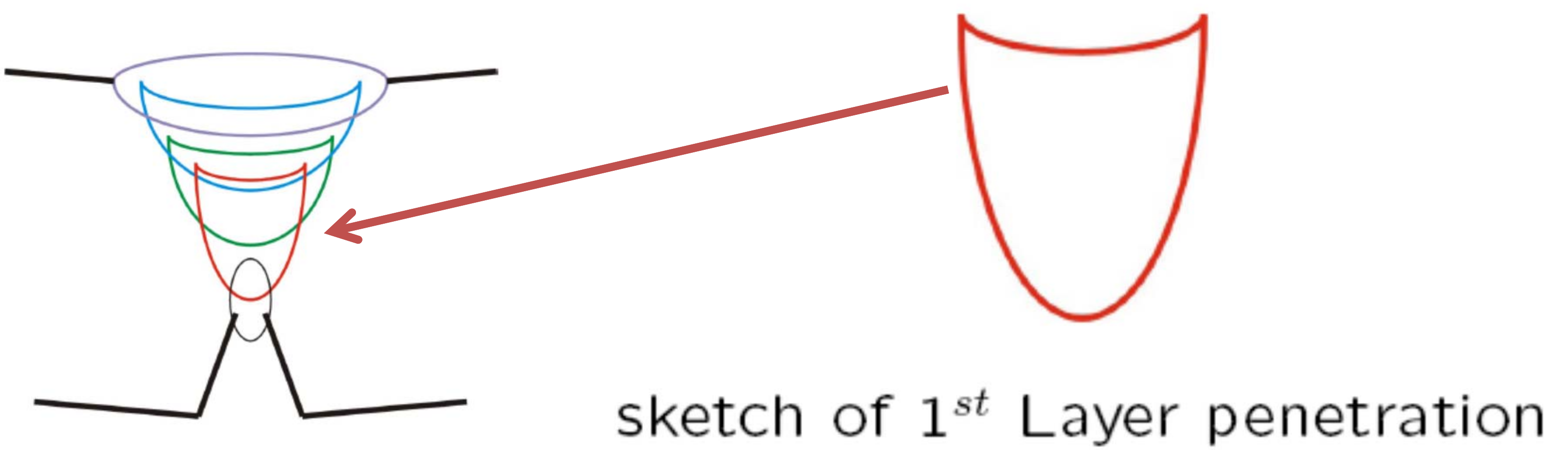
- Lead arc: DC+ 1000 amps, 32 volts
- Second arc: AC 900 amps, 35 volts
- Third arc: AC 800 amps, 38 volts
- Fourth arc: AC 725 amps, 41 volts

- All wires are 4.0 mm diameter
- All heat inputs are essentially the same

Courtesy: Lincoln Electric

4 Wire SAW Example: Lead Arc

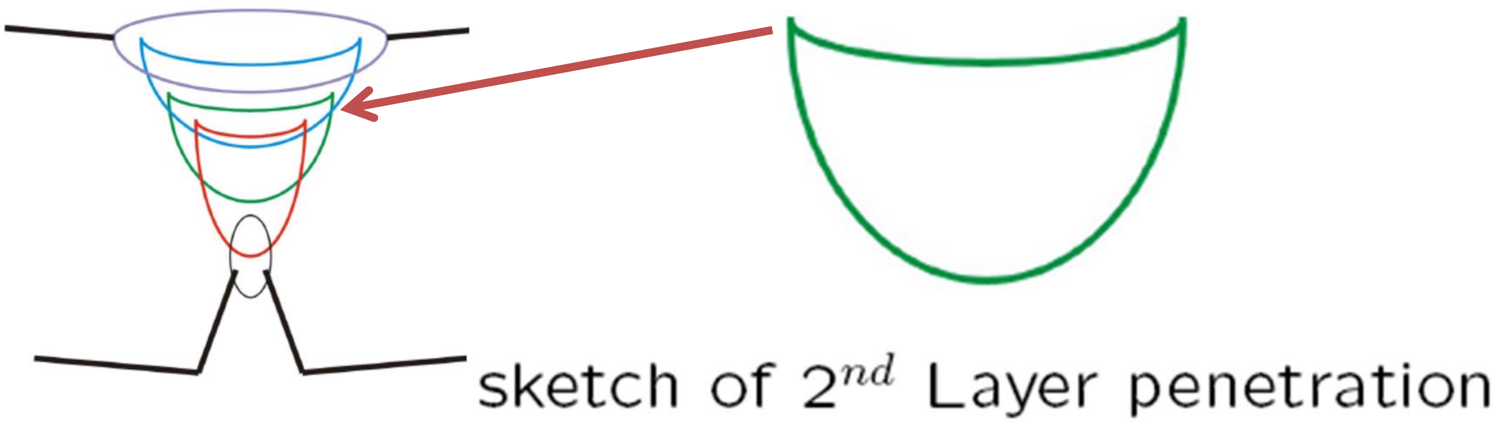
- In most cases the lead arc is DC+
- The low voltage focuses the arc current (resulting in deep penetration). Can provide up to 80% of the total penetration.



Courtesy: Lincoln Electric

4 Wire SAW Example: Arc 2

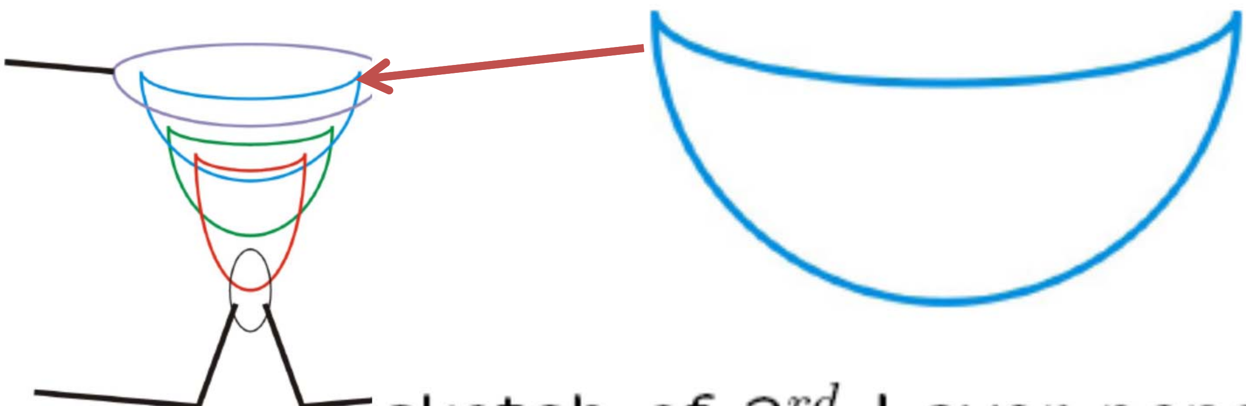
- The second arc increases penetration because of the proximity to the first arc.
- Lower current, higher voltage produces a wider, shallower bead profile.



Courtesy: Lincoln Electric

4 Wire SAW Example: Arc 3

- Current lower than Arc 2; voltage higher.
- This layer adds to the width of the bead. It should bring the weld metal approximately to the surface.

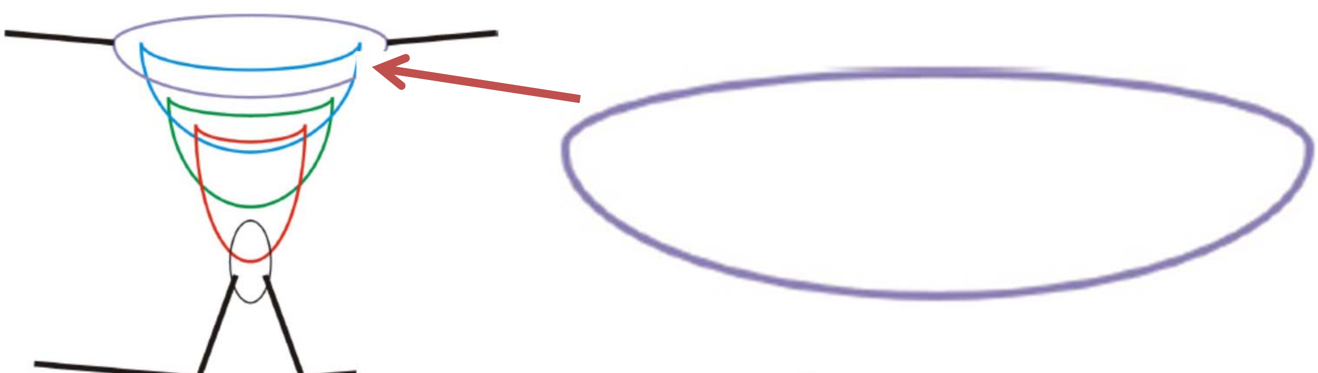


sketch of 3^{rd} Layer penetration

Courtesy: Lincoln Electric

4 Wire SAW Example: Arc 4

- Usually characterized by the lowest current and highest voltage.
- Shapes the cap of the weld. Angle of electrode, voltage, current and flux type determine toe angles, cap height, shape.

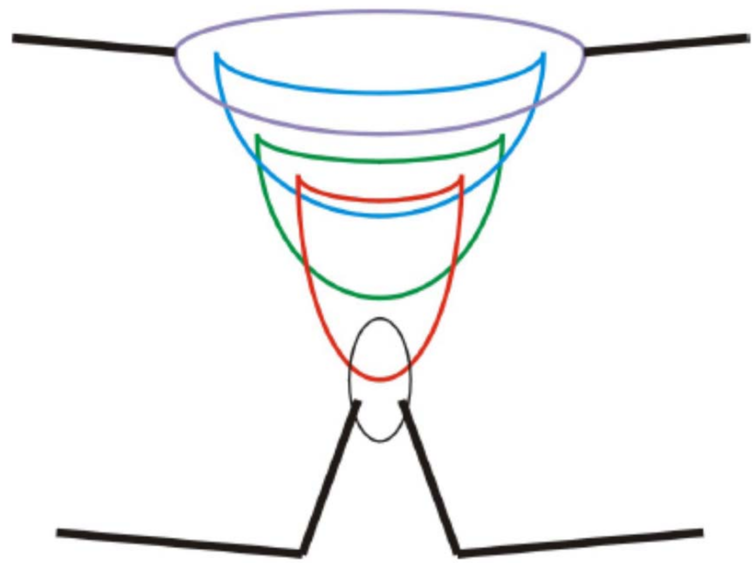


sketch of 4^{th} Layer penetration

Courtesy: Lincoln Electric

Finished Weld

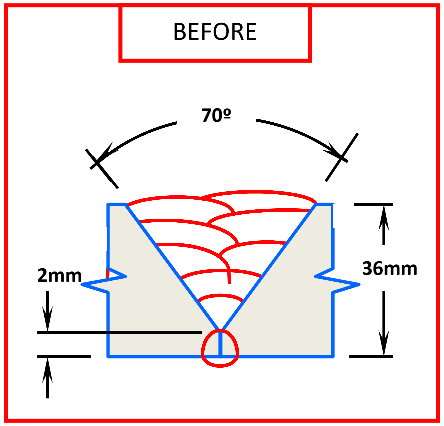
- The sketch shows the complete weld bead (with a tack weld).
- The heat input of each arc was very similar, but different shapes were created by manipulation of volts, amps, spacings and angles.

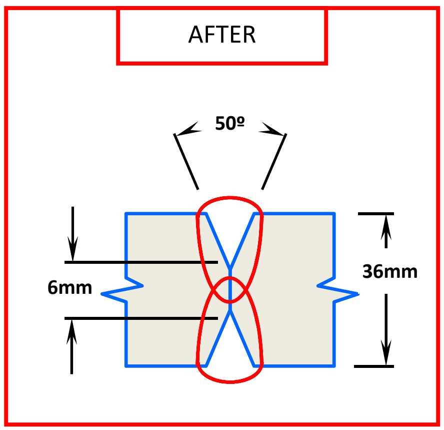


Complete fusion ID to Tack Weld

Courtesy: Lincoln Electric

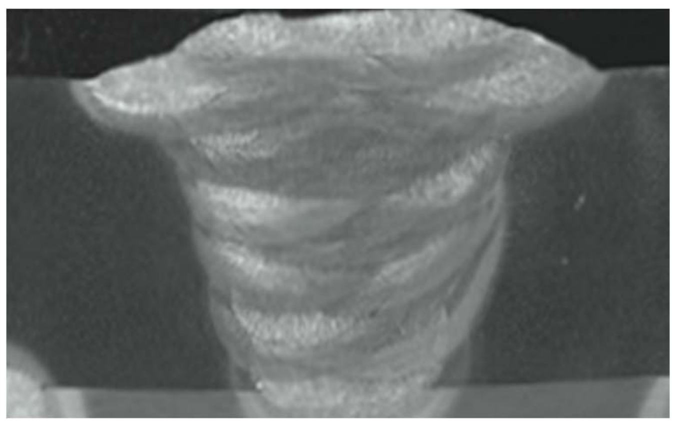
Welding Case Study

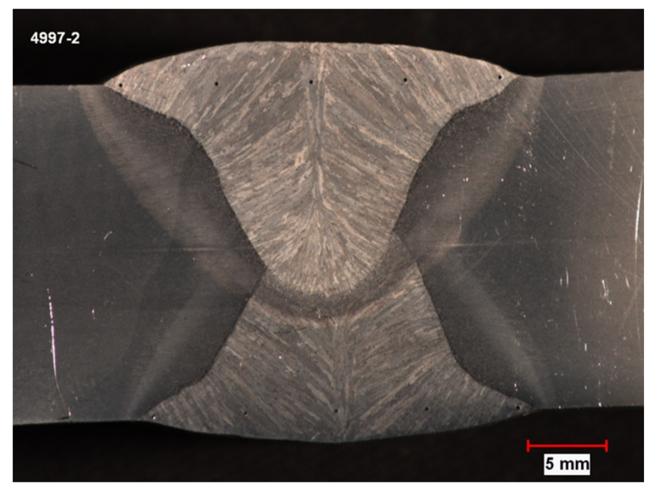




- The new procedure replaced a 9-pass single arc approach with a 2-pass tandem arc procedure
- Switched from CV to CC
- **Cost Savings – greater than 50% reduction in weld time and consumable savings**

Area of refinement



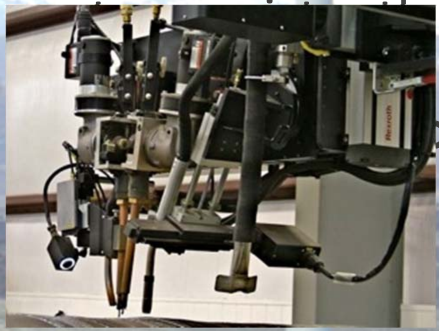


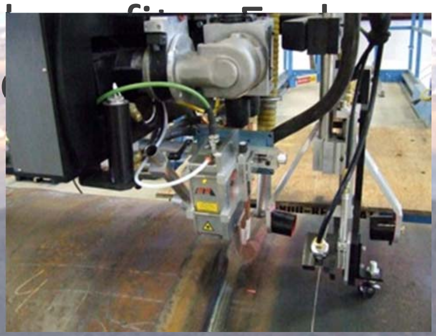
Courtesy: Lincoln Electric

Integrated Systems

An effective automation "strategy" seamlessly ties together all of the necessary components

- - Controls
- - Fixturing
- - Power Supplies
- - Sensing
- - Process Monitoring
- - Networking
- - User Interface



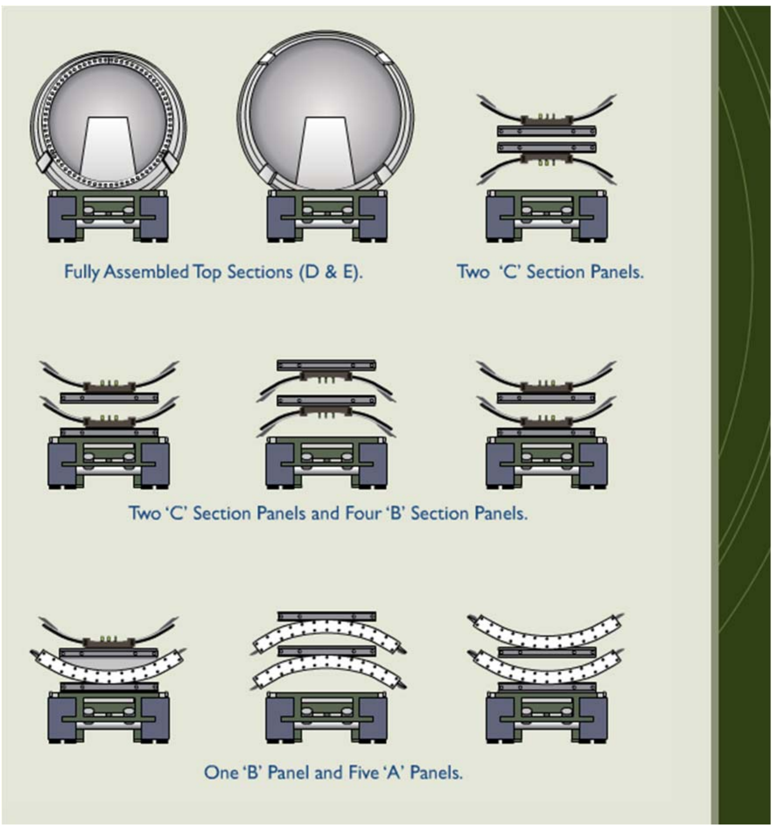


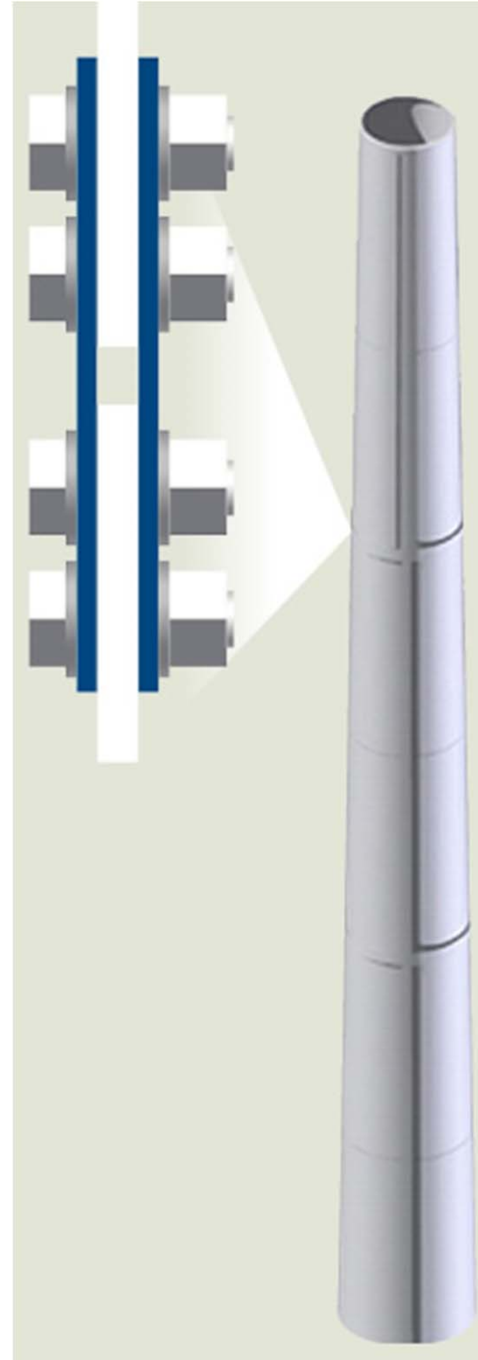
Courtesy: AMET & Lincoln Electric

As Towers get Taller. . .

- Current diameter is maximum allowed by transportation system
- On-site “fabrication/construction” of towers will be required

Modular Bolted





Cast Weld

Concrete vs. Steel

- Steel dominates U.S. market
- Some concrete tower usage in Europe
- On-site ‘concrete fabrication’ or precast segments
- Cheaper materials
- Hybrid: Steel on concrete

Metalcastings

Metalcastings

- Rotor hub
- Nacelle bed plate
- Gear box housings

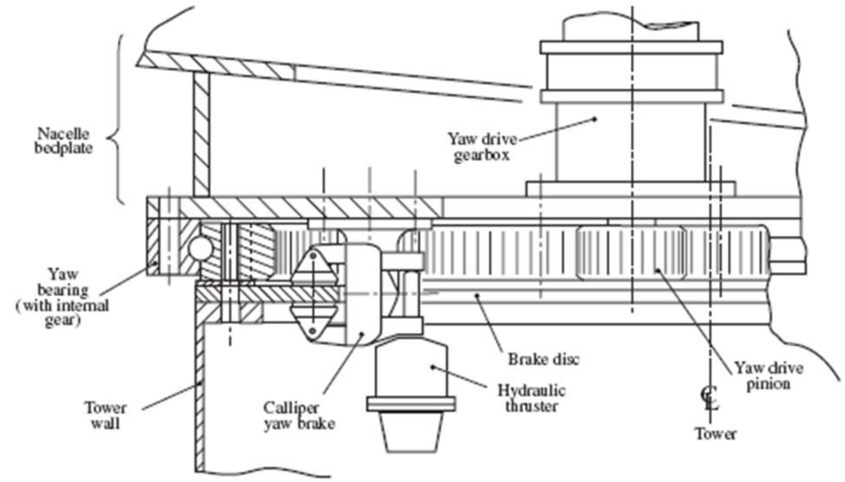
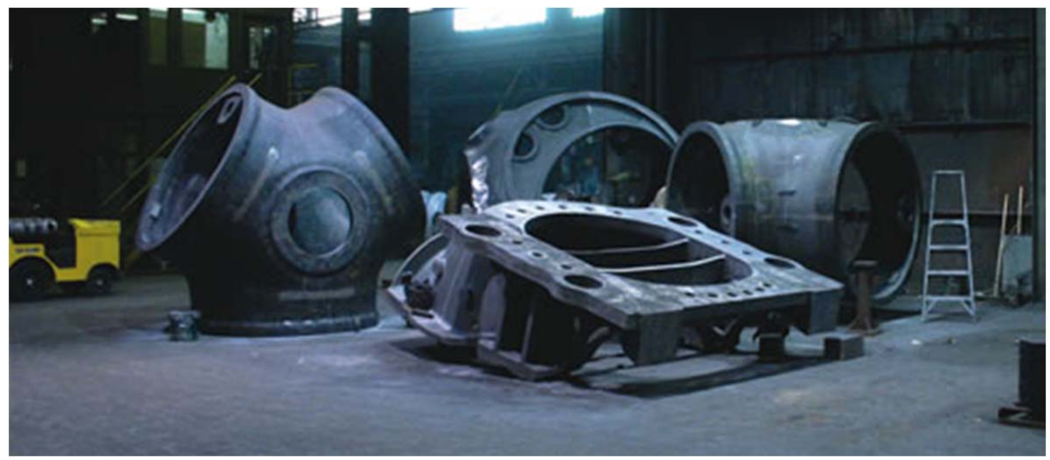


Figure 7.37 Typical Arrangement of Yaw Bearing, Yaw Drive and Yaw Brake



Sources: Wind Energy Handbook
www.hodegefoundry.com
http://www.imfluino.it/clients/casting-wind.htm

Metalcastings

- Provide superior design flexibility wrt fabrications
- Produced in chemically bonded sand molds
- Metal:
  - Currently ductile cast
  - Steel possibility

http://www.imfluino.it/clients/casting-wind.htm

Metalcastings

- Domestic casting supply base currently 1000 casting sets
- Projections are for 8000 units
- Future domestic investment in question due to current/pending environmental regulations

Rotor Casting Loading

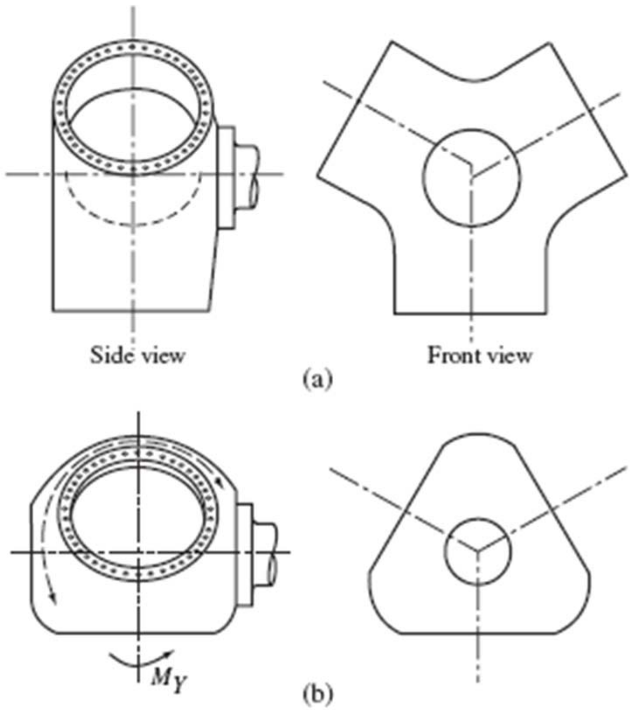


Figure 7.22 (a) Tri-cylindrical Hub; (b) Spherical Hub

- Symmetric rotor thrust loading
- Thrust loading on a single blade
- Blade gravity

My Crystal Ball. . .

- Blades
  - Mix of domestic and import
  - Mix of automation and autonomation solutions
  - Design for manufacturability
  - Decreased weight through improved manufacturing tolerances
  - Designed with ‘end-of-life’ in mind
- Towers
  - Modular construction
  - Concrete/steel hybrid
- Castings
  - Steel usage will occur
    - Opens up supply chain
    - Improved strength/weight ratio
  - Policy change needed to support domestic manufacturing