Tower and Foundation Design for Small Wind Turbines

Innovation
Design Codes and Structural Standards
Made-in-America Content

SMART Wind Consortium Virtual Meeting: Tower and Foundation Design

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Examining Goals and Objectives
(Excerpts from DWEA SMART Wind Roadmap)

"… aiding distributed wind industry growth …"

This suggests the lowest cost solution … <u>imports</u>!

"…increasing production volumes
"… reducing lifecycle costs while maintaining high quality …"
"… bolster the existing capabilities of this U.S.-led industry …"

These have neutral suggestion regarding sourcing.

"… high payoffs in the form of increased employment …"
"… creation of U.S. monopole tower supply …"
"… technology that is manufactured in the U.S. …"
"… increase employment in the sector …"

These suggest preference for made-in-America products.

Stressing industry sustainability, profitability, etc. implies an emphasis on the lowest cost of energy, because this is the market driver. But this emphasis works against made-in-America content!

What <u>should be</u> the emphasis, or is there a rational balance?

Where is the Magic Bullet?

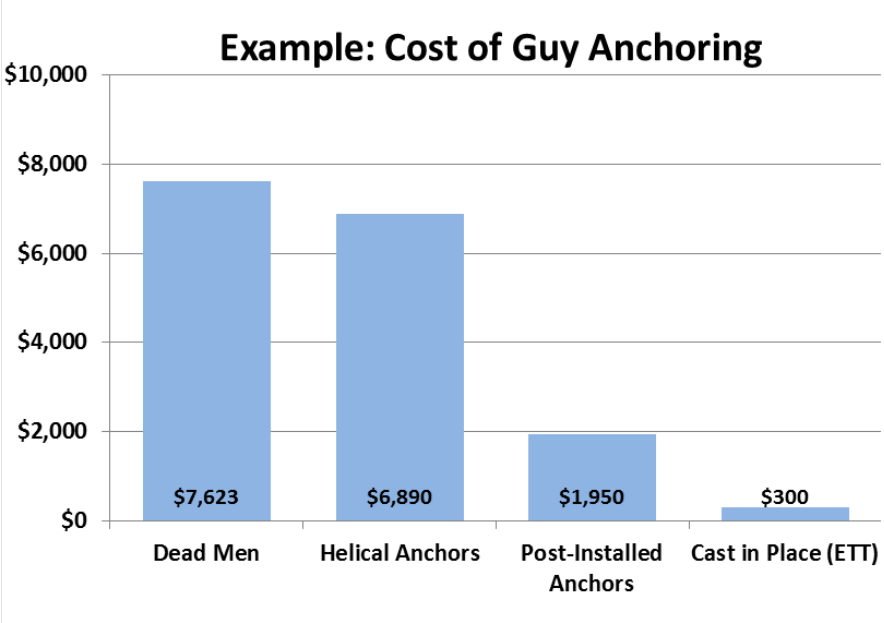
"Something that solves a difficult problem easily[1]"

"Something regarded as a magical solution or cure[2]"

Let's try this!

- Flanged Joints: Ease of assembly, but they increase the cost of monopole towers by 17% (AnemErgonics' vendor of 60' tower)
- Pre-fabricated Foundations: Nice for factory manufacturing, special soils situations, but present shipping and assembly challenges. Show me the cost analysis!
- Helical Piers / Anchors: Geotechnical report needed? Suitable soil conditions? Available contractor? Cost effective?

Ideas must be validated for value not just cleverness!



There is no magic bullet! Now what?

[1] (Merriam-Webster, LearnersDictionary.com)
[2] (thefreedictionery.com)

"System of Systems" Approach

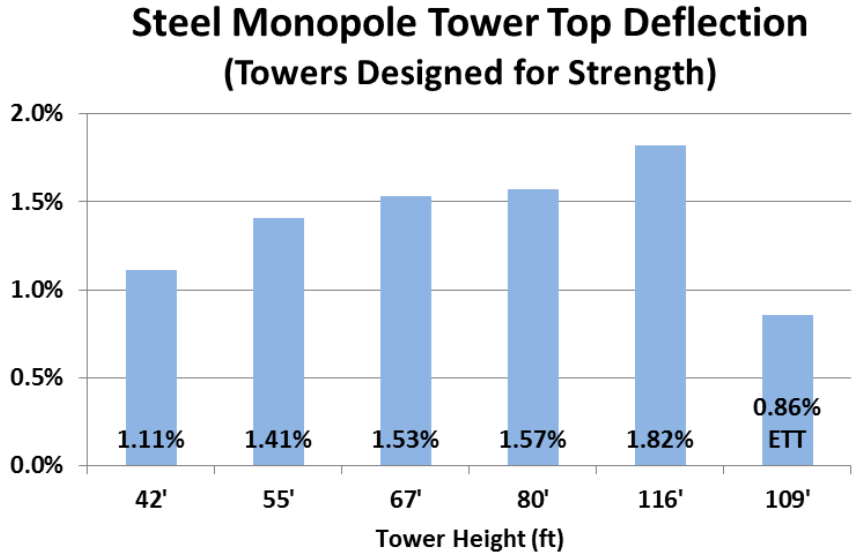
Increasing Hurdles

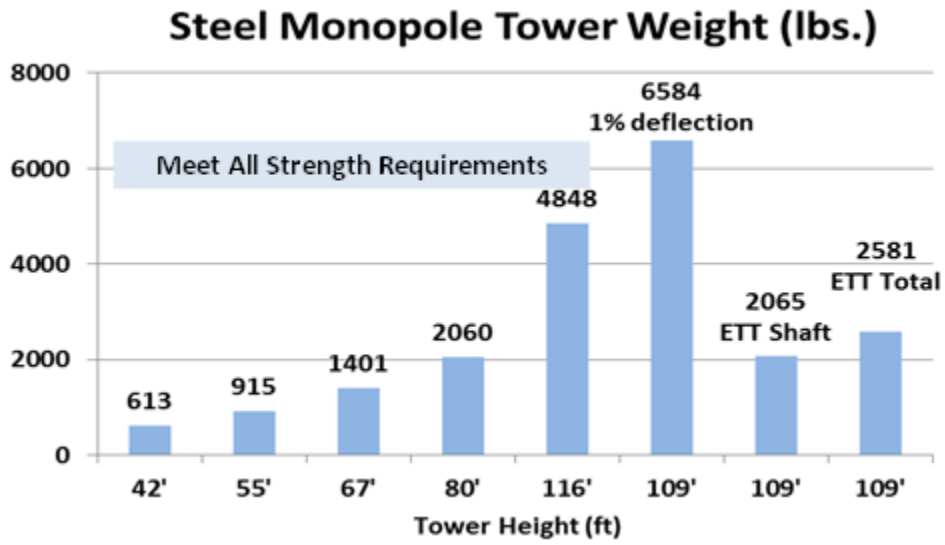
- Low Overhead
- Volume Purchasing
- Lean Manufacturing
- Insist on Level Playing Field
  - Customers must insist on equivalent products
- Solve the Shipping Cost Conundrum
  - Promise ≤ $730 to ship 60' tower anywhere in U.S.
- Shrewd Inventory Control
  - Buy long-lead / inexpensive parts in quantity
  - Bargain hunt: e.g. foundries at 15% capacity, then purchase castings.
- Judicious Compliance with Standards
  - Guidance & methods for design and manufacturing.
  - Embody conservatism; satisfy permitting authorities.
  - Forestall liability issues ***… danger lurks***.
- Innovation
  - But it must lead to compelling advantage
- Vertical Integration
- Sell Direct to Installers
- Lower Margins
  - Assume tower = 35% of ICC.
  - Equal margin on tower, turbine, and installation.
  - 33% tower margin = 21.2% impact on LCOE
  - 50% tower margin = 31.8% impact on LCOE
- Technology Licensing
- Made-in-America Consortium

Every ounce of creativity is necessary.

Design Codes and Structural Standards

- Did you know that TIA-222-G-05 etc. requires …..?
  - Safety factor on loads = 1.6 compared to IEC = 1.35.
  - Tower top deflection ≤ 1% of tower height at 60 mph (unless system dynamic analysis is reassuring).
  - Guy assemblies with factory-installed end fittings must be pre-stressed and proof loaded.
  - Brake-formed steel towers require full-penetration seam welds near flanges or slip-fit joints.





Examples of Innovation_1

AnemErgonics' SMarT Foundations® (U.S. Patented)

- No forms, no rebar, pre-engineered, and "kits" easily ship anywhere.
- But limited in size and seismic zones A and B only

Illustrative Cost Savings for SMarT [1] Foundations

Cost Element	Traditional Mat	SMarT Foundation	Savings (%)	Savings ($)
Pre-Construction Labor Hours	7.0	5.5		
On-Site Construction Labor Hours	27.5	10.25		
Total Labor Hours	34.5	15.75	-54%	
Blended Hourly Labor Rate ($)	40	40		
Total Labor Cost ($)	1380	630		
[2] Materials and Equipment Cost ($)	3079	2402	-32%	
Material, Equipment and Labor Cost	4459	3032		-1427

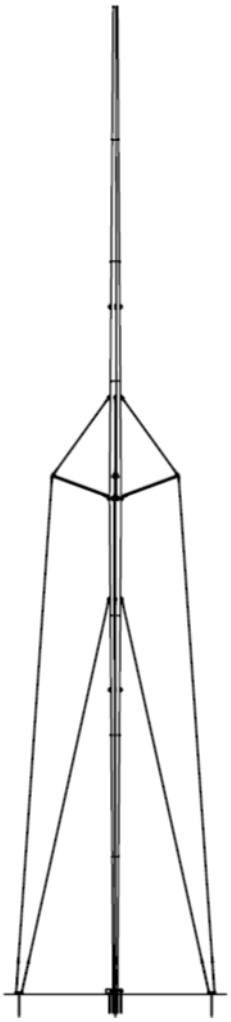
[1] Simple Modular Technology
[2] Concrete, rebar, anchor rods, forms excavator rental, sales tax

This succeeds because of compelling cost and convenience advantages.

Examples of Innovation_2

(ETT) Exoskeleton Tall Tower (U.S. Patent Pending)

- Partial support from DOE Phase I SBIR grant.
- Checkmarks indicate critical design issues.
- Much smaller footprint than guyed tower.
- Light weight allows tilt-up installation.
- No crane or similar equipment.
- Less expensive than free-standing monopole.
- More complex than free-standing, and ….
- Only economical for tall towers.
- ***This <u>may</u> succeed because of compelling cost and installation advantages.***



[1] "SMART Wind Roadmap: A Consensus-Based, Shared-Vision, Sustainable Manufacturing, Advanced Research & Technology Action Plan for Distributed Wind," DWEA (Distributed Wind Energy Association)," Oct. 2015, p.13
[2] AnemErgonics, LLC Final Technical Report, "An Exoskeleton Tall Tower Option for Small Wind Turbines," Award Number DE-SC0011964, Period of Performance Ending April 30, 2015

AnemErgonics Exoskeleton Tall Tower (ETT) With and Without Some Off-Shore Components

	DWEA Typical 10-kW Turbine 37-meter Self-Supporting [1] Lattice Tower	AnemErgonics 33-Meter ETT Tower [2] (100% USA Content)	AnemErgonics 33-Meter ETT Tower [2] (Imported Cable Components)
Tower	$26,995	$20,188	$18,901
Foundation	$14,000	$6,253	$6,253
Setup/Crane	$2,800	$1,344	$1,344
Shipping & Delivery	$2,000	$1,509	$1,509
Permit & Misc.	$1,000	$640	$621
Total Cost	$46,795	$29,934	$28,628
Initial Capital Cost	100%	**64.0%**	**61.2%**

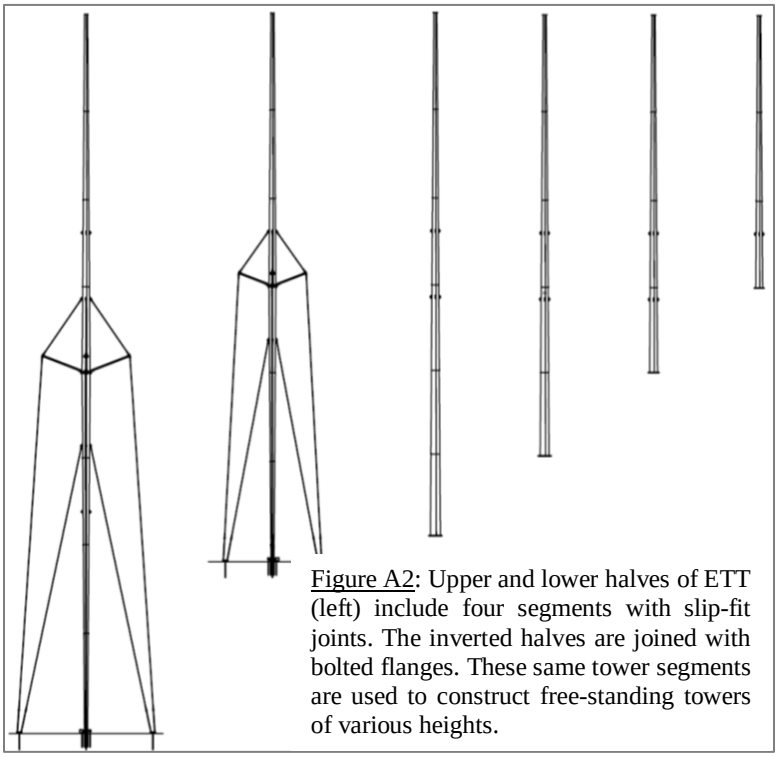


Figure A2: Upper and lower halves of ETT (left) include four segments with slip-fit joints. The inverted halves are joined with bolted flanges. These same tower segments are used to construct free-standing towers of various heights.

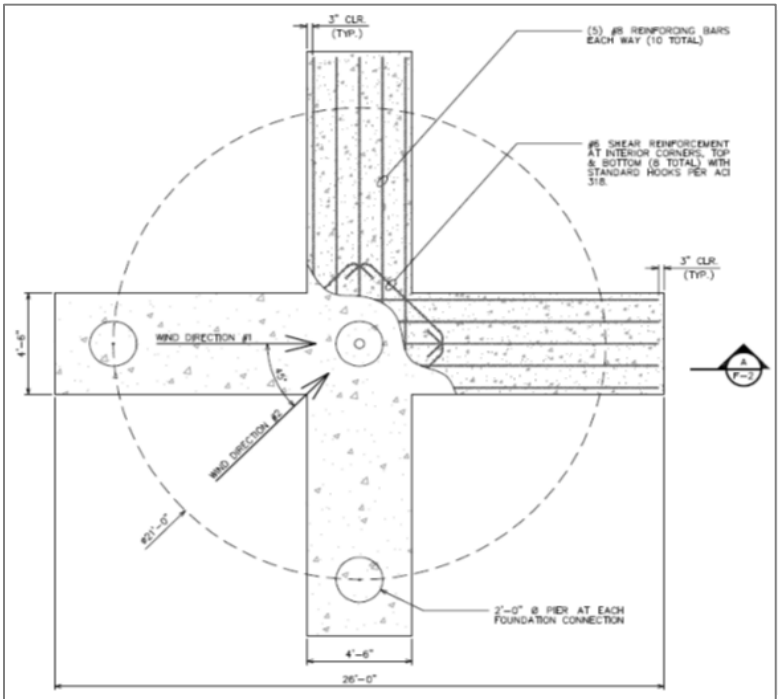
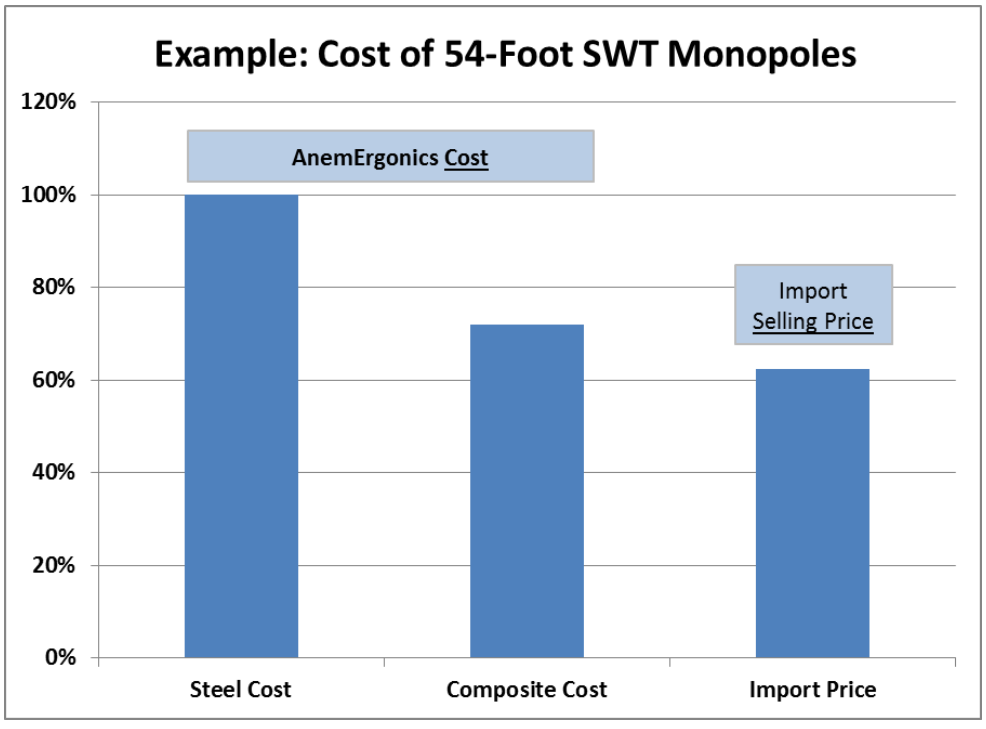


Figure A3: ETT purpose-designed foundation shown for illustration (disregard notes). Because the guy anchors always load the foundation legs in tension, only one rebar mat is required at the base of the excavation. Orthogonal rebar members are not required. These features dramatically reduce labor, material, and excavation costs.

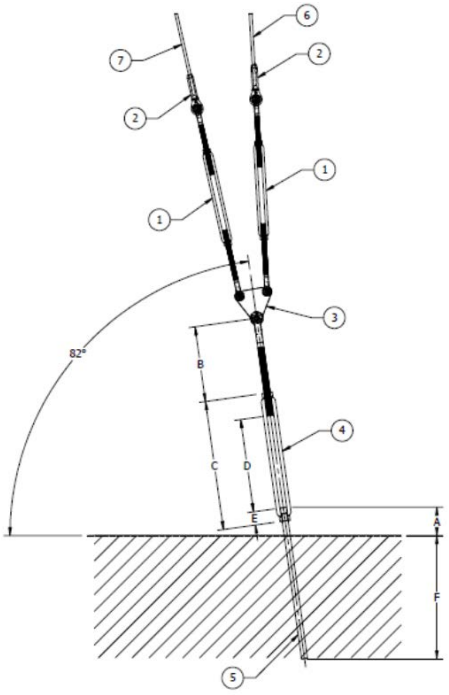
Examples of Innovation_3
AnemErgonics SMarT Towers®

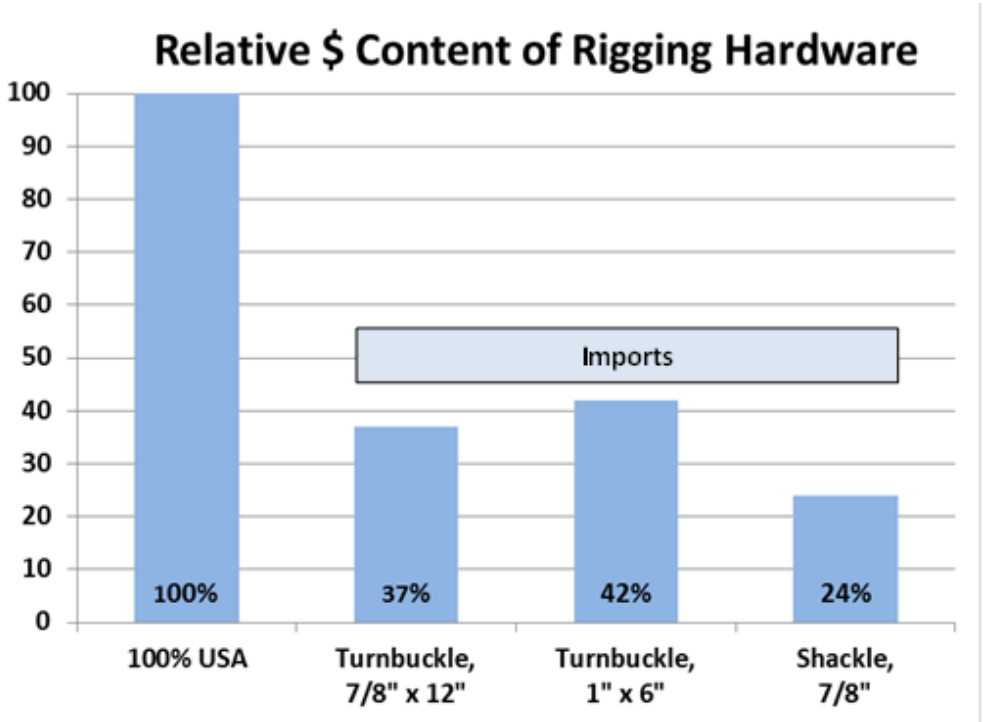
- FRP-polyester; 1/4 the cost of FRP-epoxy.
- 1/4 the weight of steel, but 1/8 the stiffness.
- Stronger than steel, but larger safety factors.
- Tower base/top adapter ductile iron castings.
- ≥ 80,000 hours with Skystream at NWTC.
- ≥ 35,000 hours with Pika T701 at the NWTC.
- Warranty against environmental degradation.
- One failure due to unanticipated tower-turbine dynamic loads.
- Tower, foundation kit, hinge plates, shipping anywhere in the U.S.
    - $4,997 for 41' and $6,594 for 53' SMarT Tower for "Puffin".

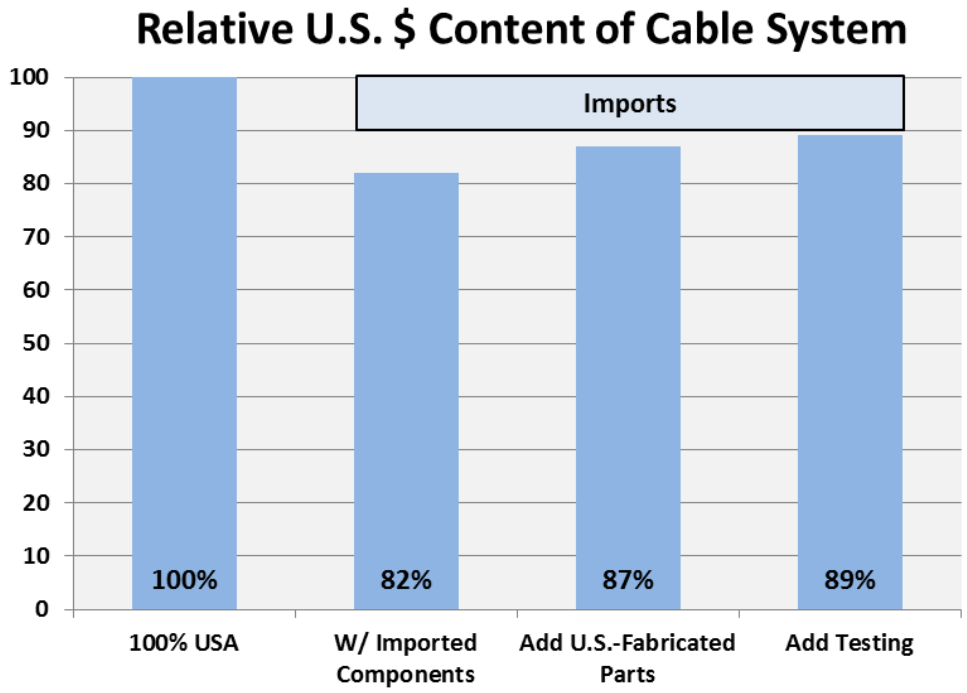


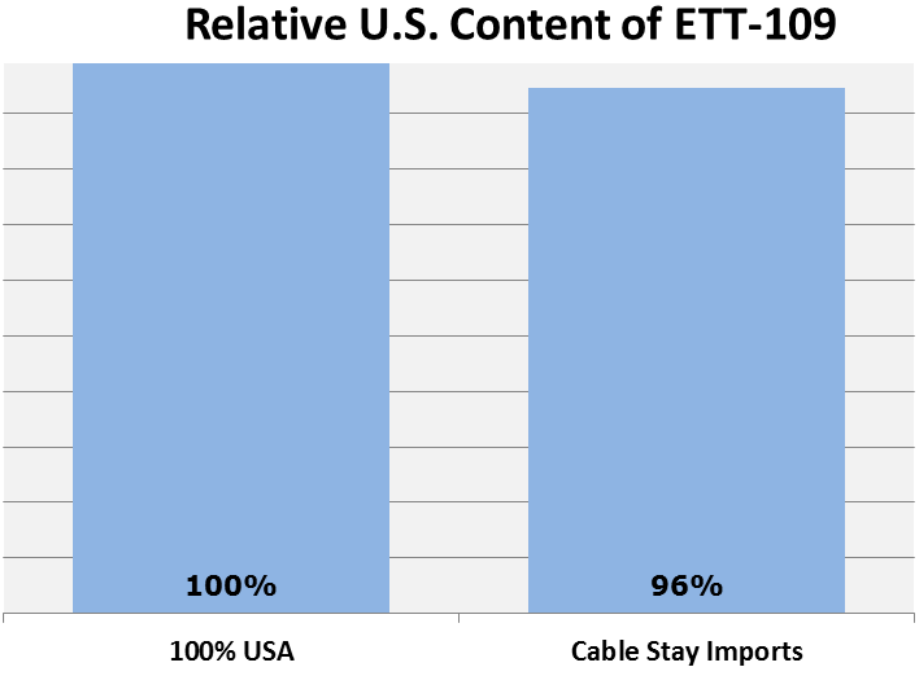
Innovative and cost effective but difficult to compete because product is purely labor + materials … so cheap from China!

Some Observations on the Relative U.S. Content of SWT Tower Systems









Made-in-America content varies dramatically by component, subsystem and the entire system.

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