NuMAD Cost Tool:
Summer Internship Summary

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Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Introduction

- Ph.D. Student, Univ. of Massachusetts Amherst
- Lab Affiliations: Wind Energy Center / Sustainable Building Materials Group
- Academic Thrust Areas: Materials Science and Wind Energy
- Dissertation Topic: Integration of Bio-based Materials into Megawatt-Scale Wind Turbine Blades

Project Goals

- Review and summarize existing blade manufacturing cost models
- Identify cost model requirements for integration with SNL design tools and adapt from existing design tools
- Modify NuMAD to integrate new cost model
- Do a blade cost study to demonstrate/validate tool

Presentation Outline

- Summary of existing cost models
- Motivation/Development of NuMAD cost tool
- Tool Validation
- Demonstration: Parametric Analyses
- Future Work

Existing Cost Models

Tool/Model/Author	Year	public?	fidelity	scaling	format	strengths, limitations, notes
WindPACT (SNL/TPI)	2003	Y	low-med	limited	Report/ TP quotes	manufacturing scaling and trends analysis; somewhat outdated
NREL Cost and Scaling	2006	Y	low	yes	excel	trends analysis; looks at entire turbine; very little detail
Fraunhofer IWES		N	med	yes	excel	non-US reference; automation analyses
SNL / Johanns-Griffith	2013	Y	high- labor med-materials	yes	excel	high fidelity labor
NREL / James-Goodrich	2013	N	multi	yes	excel	considers financing; labor based on SNL (2013)
TPI / Nolet	2014	N	med	no	excel	industry experience; current data; includes CAPEX
NREL / Berry	IP	N	high	IP	excel	very thorough materials analysis; other components currently unfinished

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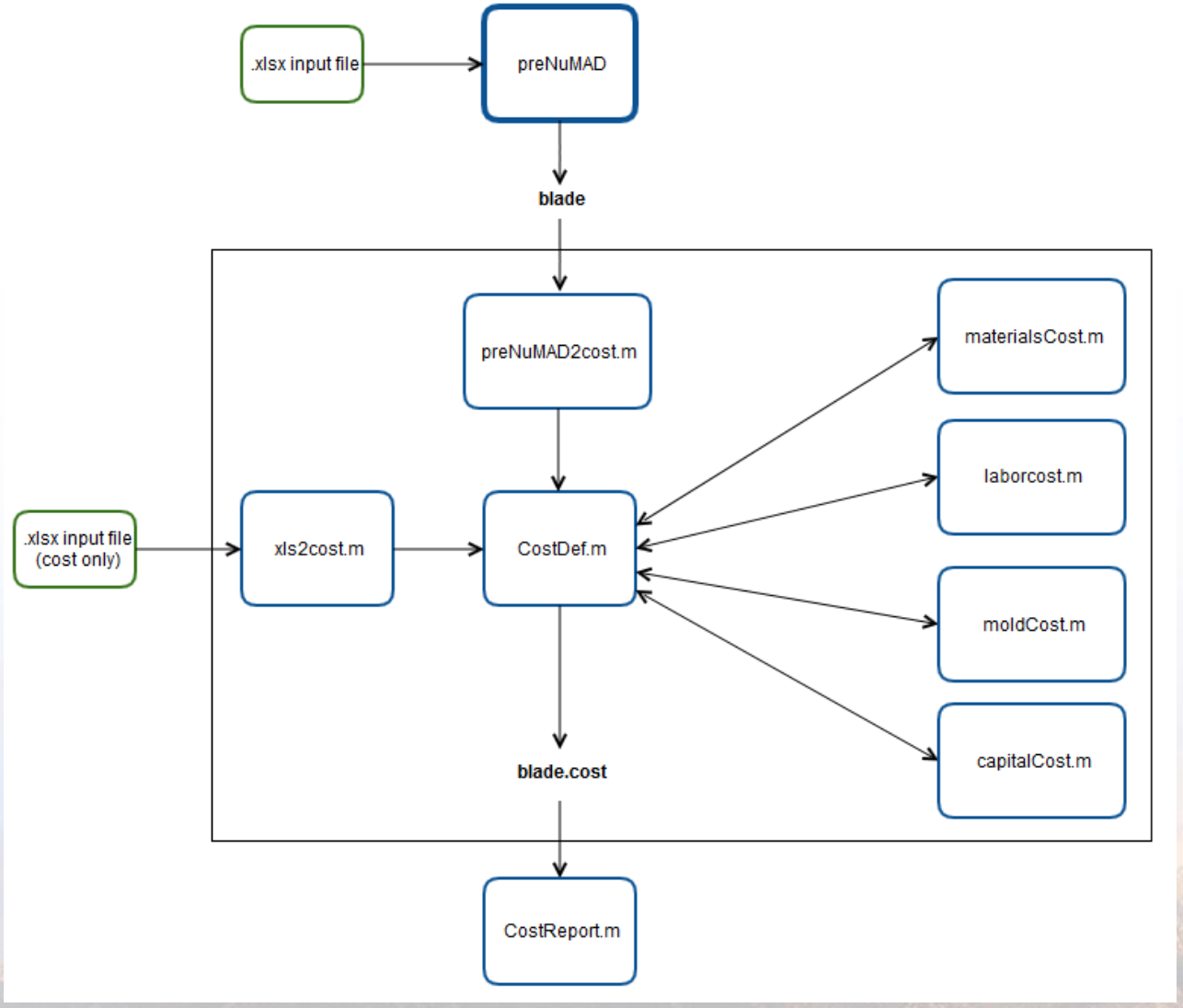
Cost Tool Priorities

- Integration with NuMAD
- Highly automated for optimization
- Medium-high fidelity
- Format to integrate with other blade design tools
- Low CPU time
- Minimal changes to existing NuMAD codes and interfaces

Aside: Current State of NuMAD

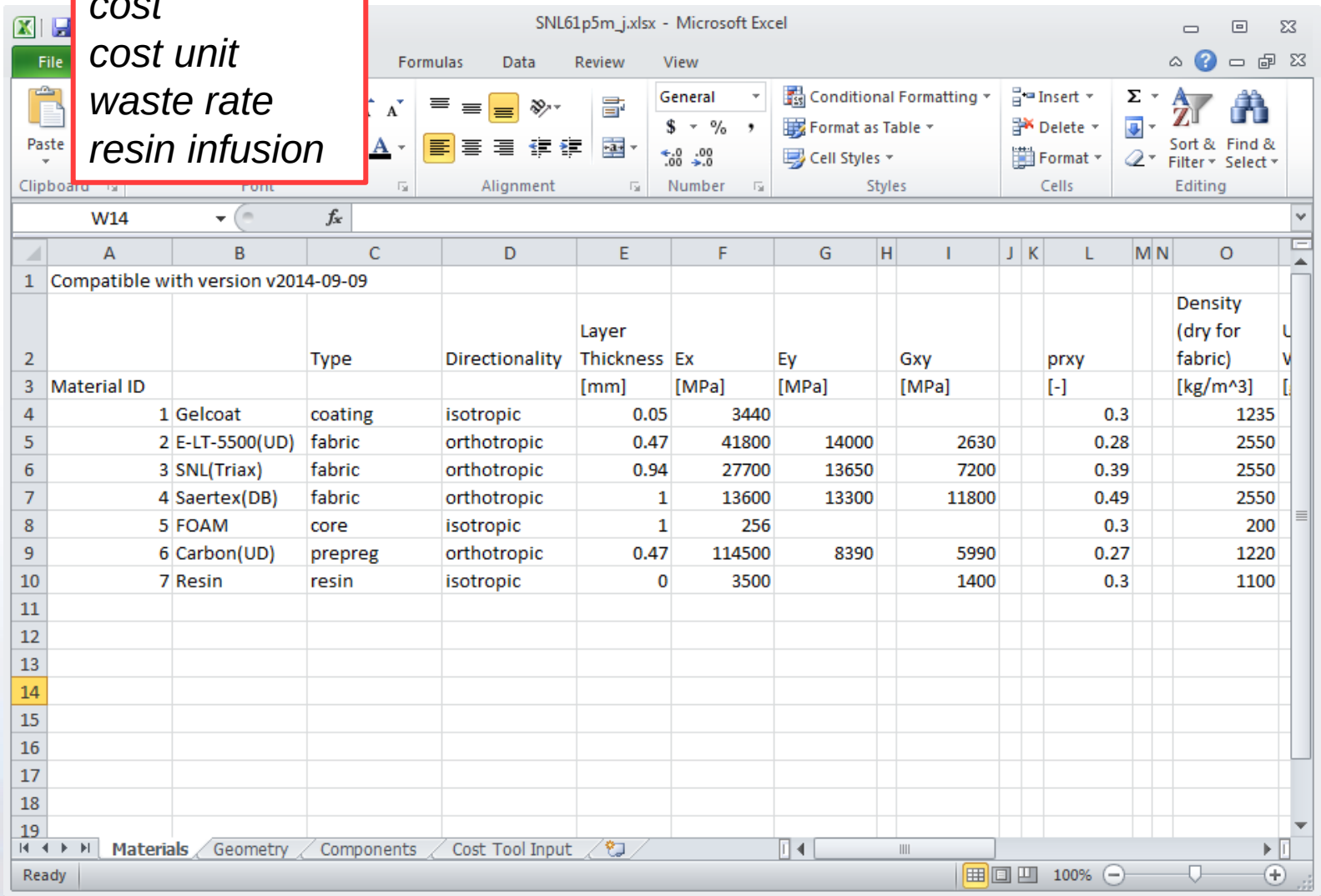
- **preNuMAD: move to object-oriented programming**
  - motivations included incorporation of a cost tool
  - improved ability to manage software complexity
  - improved efficiency
- **blade object**
  - properties, e.g. blade.sparcapwidth, blade.materials, blade.materials(6).density
  - methods, e.g. blade.generateCost, blade.generateCostReport
- **currently, blade object is defined manually or in excel input (xlsBlade.m) and gets converted back to NuMAD**

Integrated Blade Cost Tool



Cost Tool Input

added fields:
type
cost
cost unit
waste rate
resin infusion



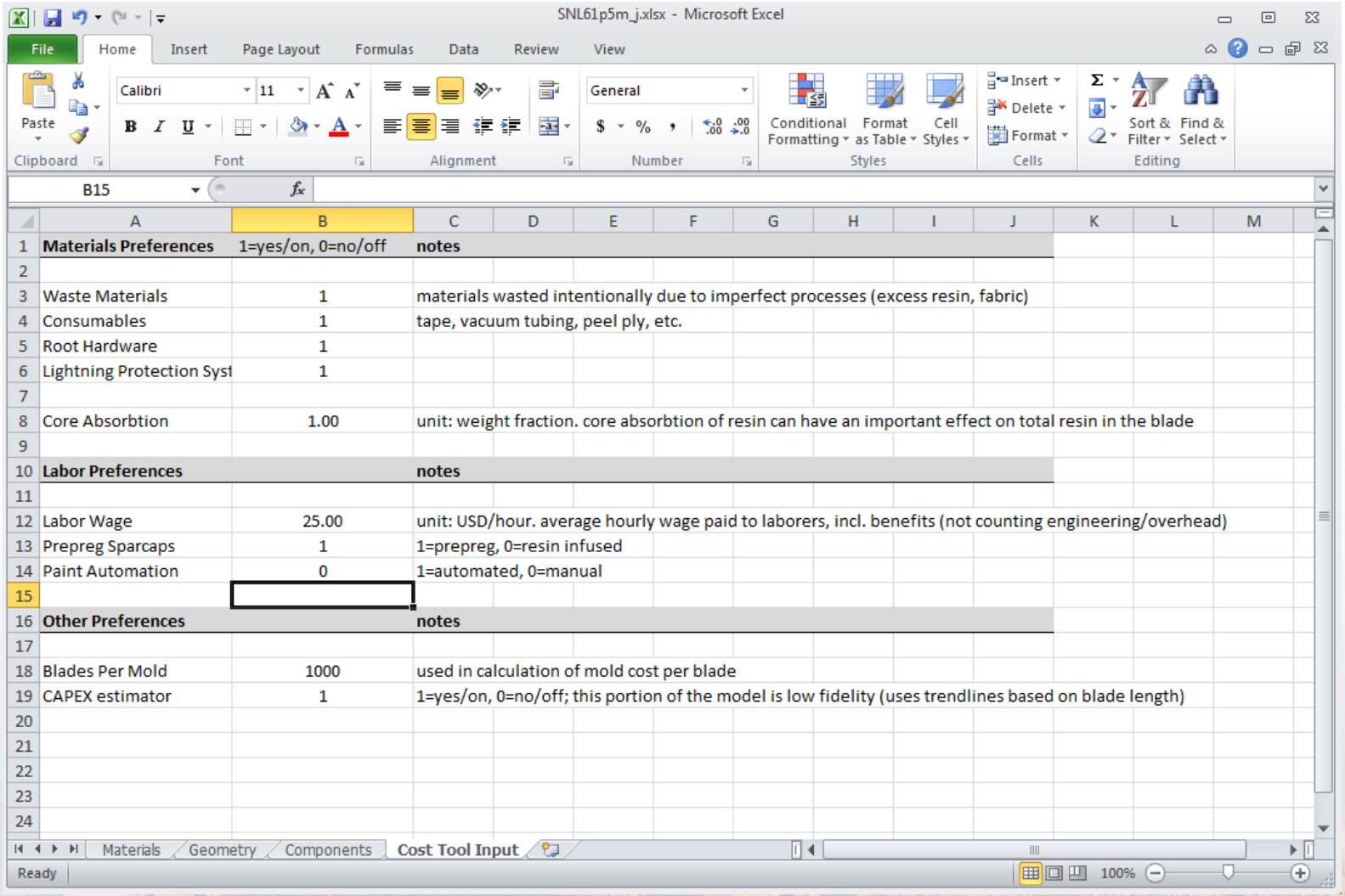
SNL61p5m_j.xlsx - Microsoft Excel

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	Compatible with version v2014-09-09														
2			Type	Directionality	Layer Thickness	Ex	Ey		Gxy			prxy			Density (dry for fabric)
3	Material ID				[mm]	[MPa]	[MPa]		[MPa]			[-]			[kg/m^3]
4	1	Gelcoat	coating	isotropic	0.05	3440						0.3			1235
5	2	E-LT-5500(UD)	fabric	orthotropic	0.47	41800	14000		2630			0.28			2550
6	3	SNL(Triax)	fabric	orthotropic	0.94	27700	13650		7200			0.39			2550
7	4	Saertex(DB)	fabric	orthotropic	1	13600	13300		11800			0.49			2550
8	5	FOAM	core	isotropic	1	256						0.3			200
9	6	Carbon(UD)	prepreg	orthotropic	0.47	114500	8390		5990			0.27			1220
10	7	Resin	resin	isotropic	0	3500			1400			0.3			1100

Materials | Geometry | Components | Cost Tool Input

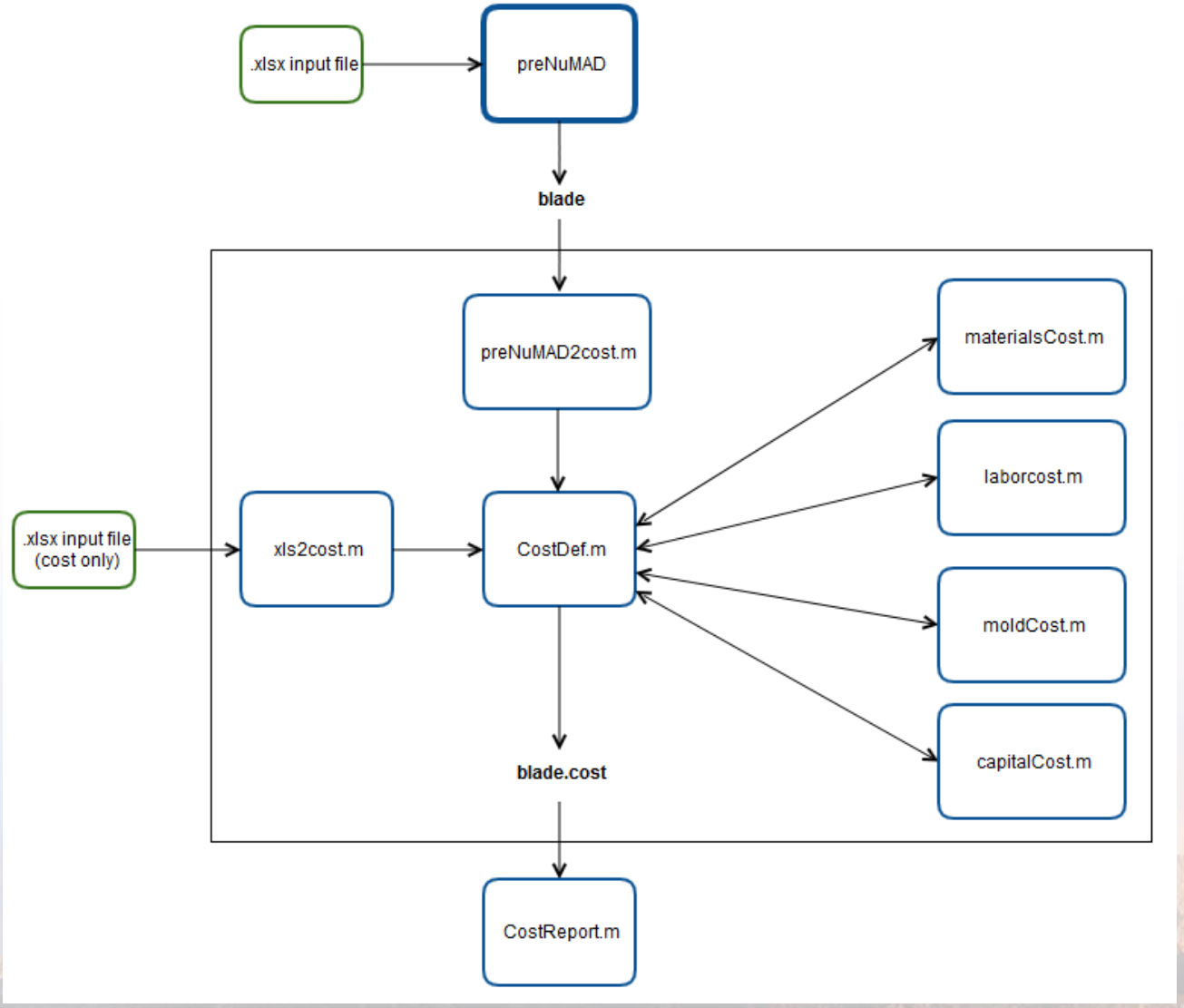
Ready

Cost Tool Input



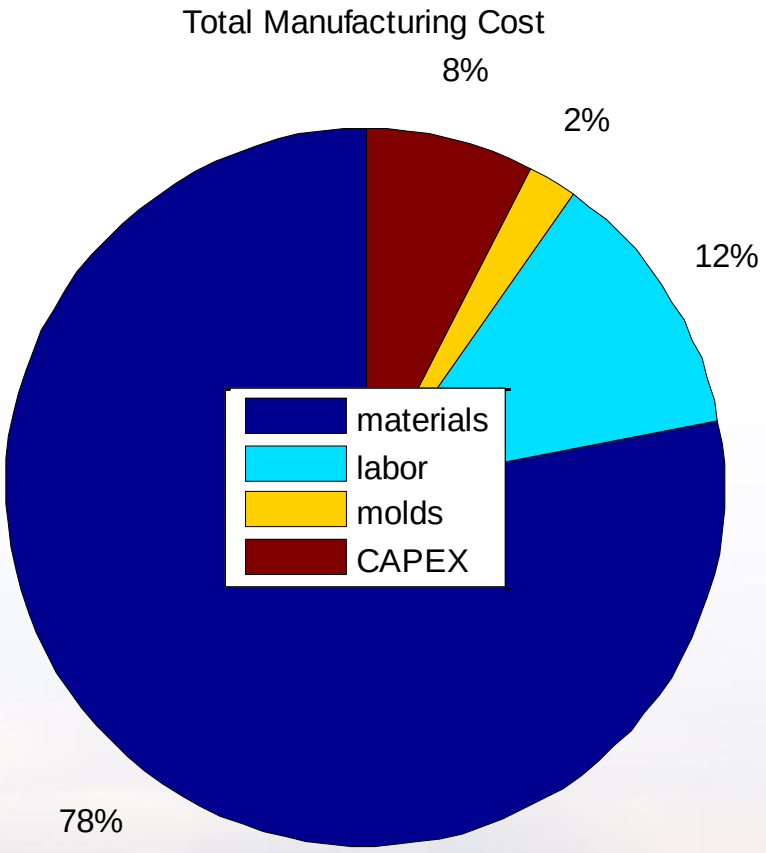
	A	B	C
1	**Materials Preferences**	1=yes/on, 0=no/off	**notes**
2			
3	Waste Materials	1	materials wasted intentionally due to imperfect processes (excess resin, fabric)
4	Consumables	1	tape, vacuum tubing, peel ply, etc.
5	Root Hardware	1	
6	Lightning Protection Syst	1	
7			
8	Core Absorbtion	1.00	unit: weight fraction. core absorbtion of resin can have an important effect on total resin in the blade
9			
10	**Labor Preferences**		**notes**
11			
12	Labor Wage	25.00	unit: USD/hour. average hourly wage paid to laborers, incl. benefits (not counting engineering/overhead)
13	Prepreg Sparcaps	1	1=prepreg, 0=resin infused
14	Paint Automation	0	1=automated, 0=manual
15			
16	**Other Preferences**		**notes**
17			
18	Blades Per Mold	1000	used in calculation of mold cost per blade
19	CAPEX estimator	1	1=yes/on, 0=no/off; this portion of the model is low fidelity (uses trendlines based on blade length)
20			
21			
22			
23			
24			

Integrated Blade Cost Tool



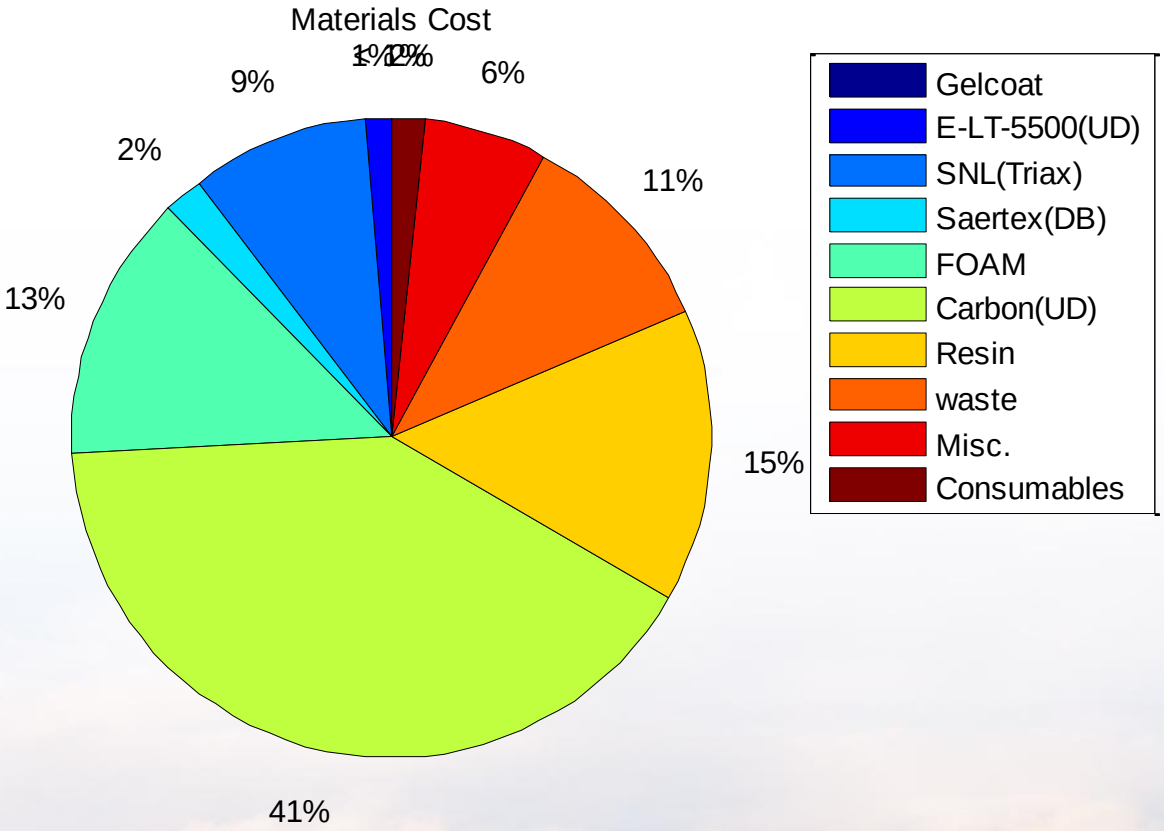
Cost Report Output

SNL 5MW 61.5m Carbon Spar



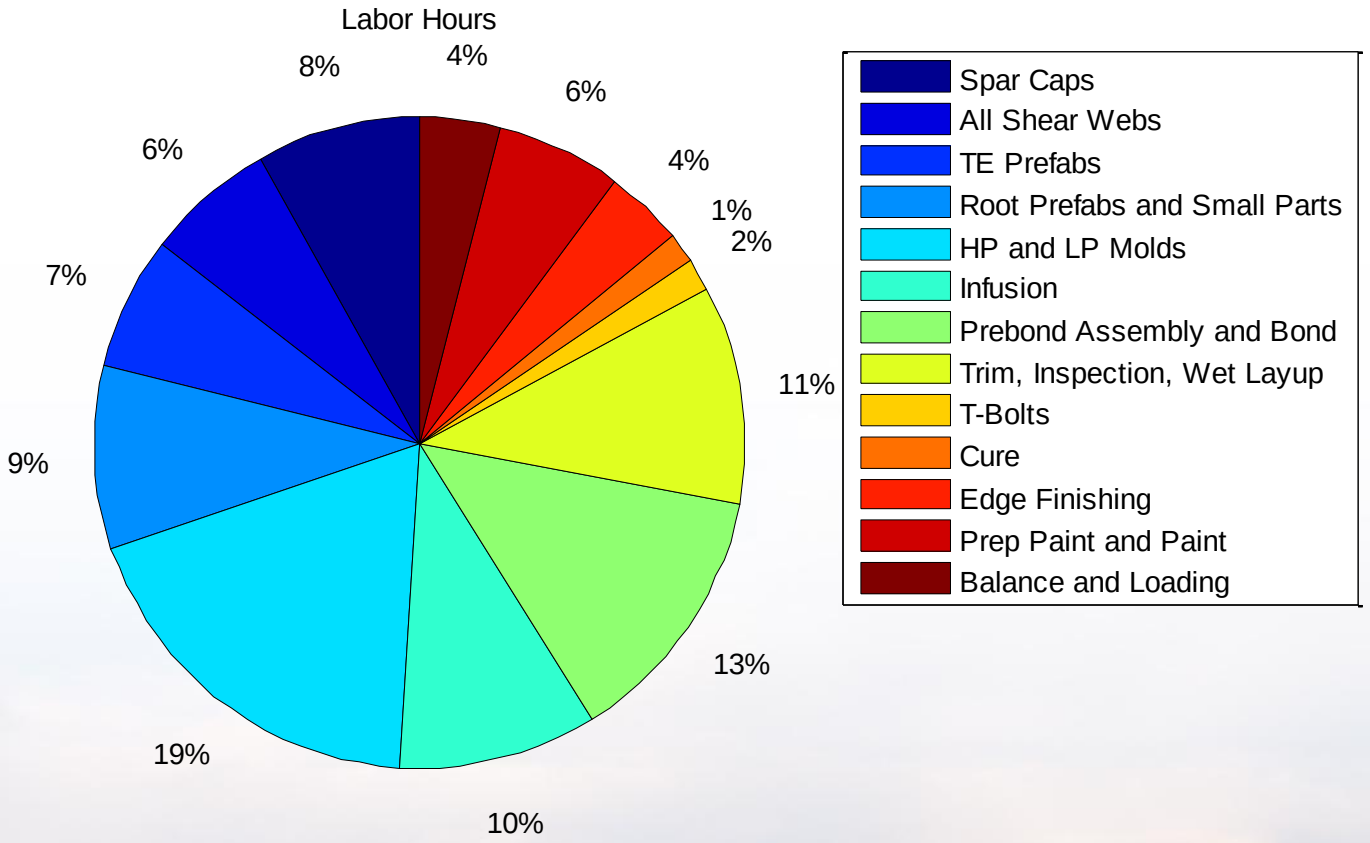
Cost Report Output

SNL 5MW 61.5m Carbon Spar



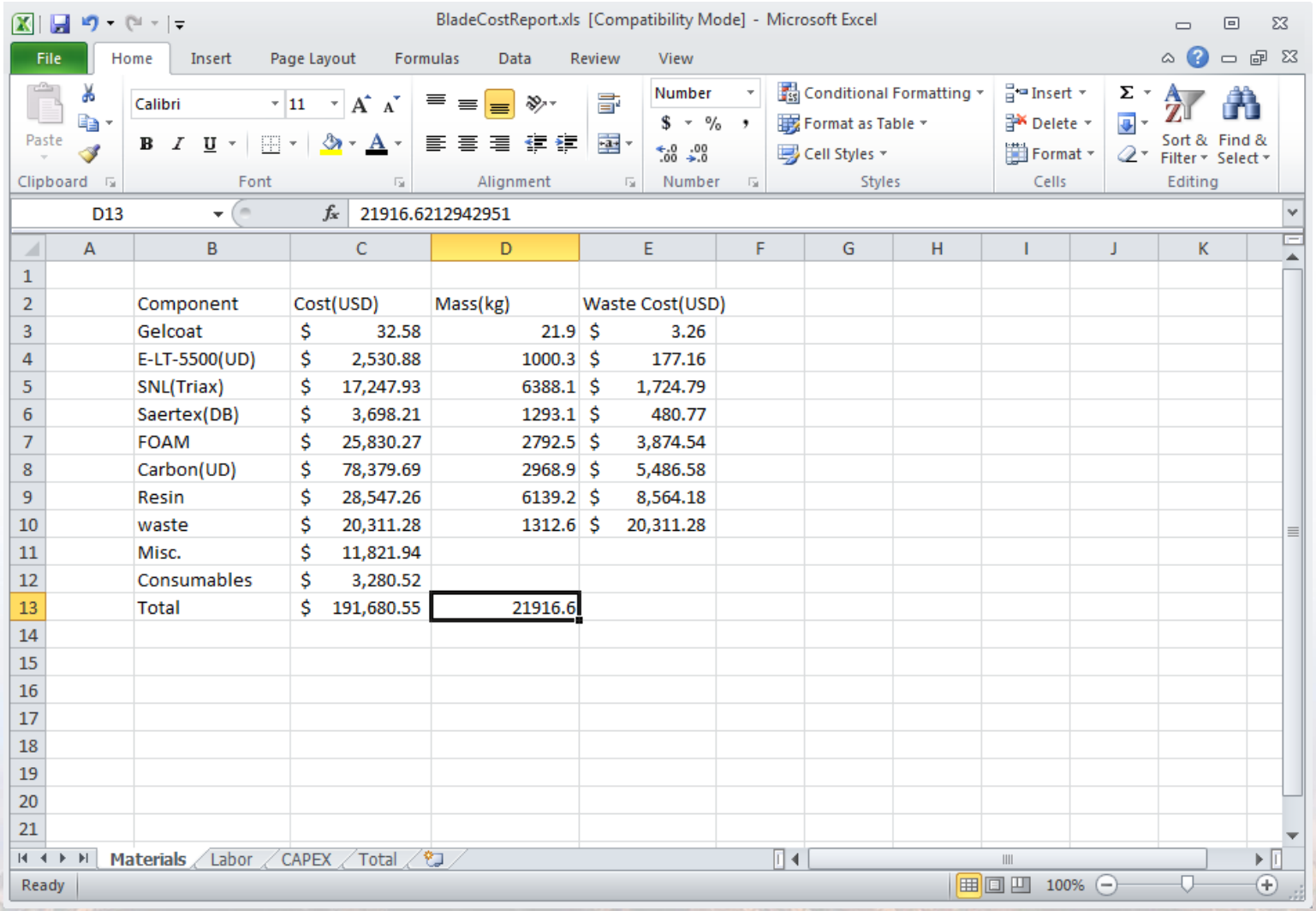
Cost Report Output

SNL 5MW 61.5m Carbon Spar



Cost Report Output

SNL 5MW 61.5m Carbon Spar



	A	B	C	D	E	F	G	H	I	J	K
1											
2		Component	Cost(USD)	Mass(kg)	Waste Cost(USD)						
3		Gelcoat	$ 32.58	21.9	$ 3.26						
4		E-LT-5500(UD)	$ 2,530.88	1000.3	$ 177.16						
5		SNL(Triax)	$ 17,247.93	6388.1	$ 1,724.79						
6		Saertex(DB)	$ 3,698.21	1293.1	$ 480.77						
7		FOAM	$ 25,830.27	2792.5	$ 3,874.54						
8		Carbon(UD)	$ 78,379.69	2968.9	$ 5,486.58						
9		Resin	$ 28,547.26	6139.2	$ 8,564.18						
10		waste	$ 20,311.28	1312.6	$ 20,311.28						
11		Misc.	$ 11,821.94								
12		Consumables	$ 3,280.52								
13		Total	$ 191,680.55	21916.6							
14											
15											
16											
17											
18											
19											
20											
21											

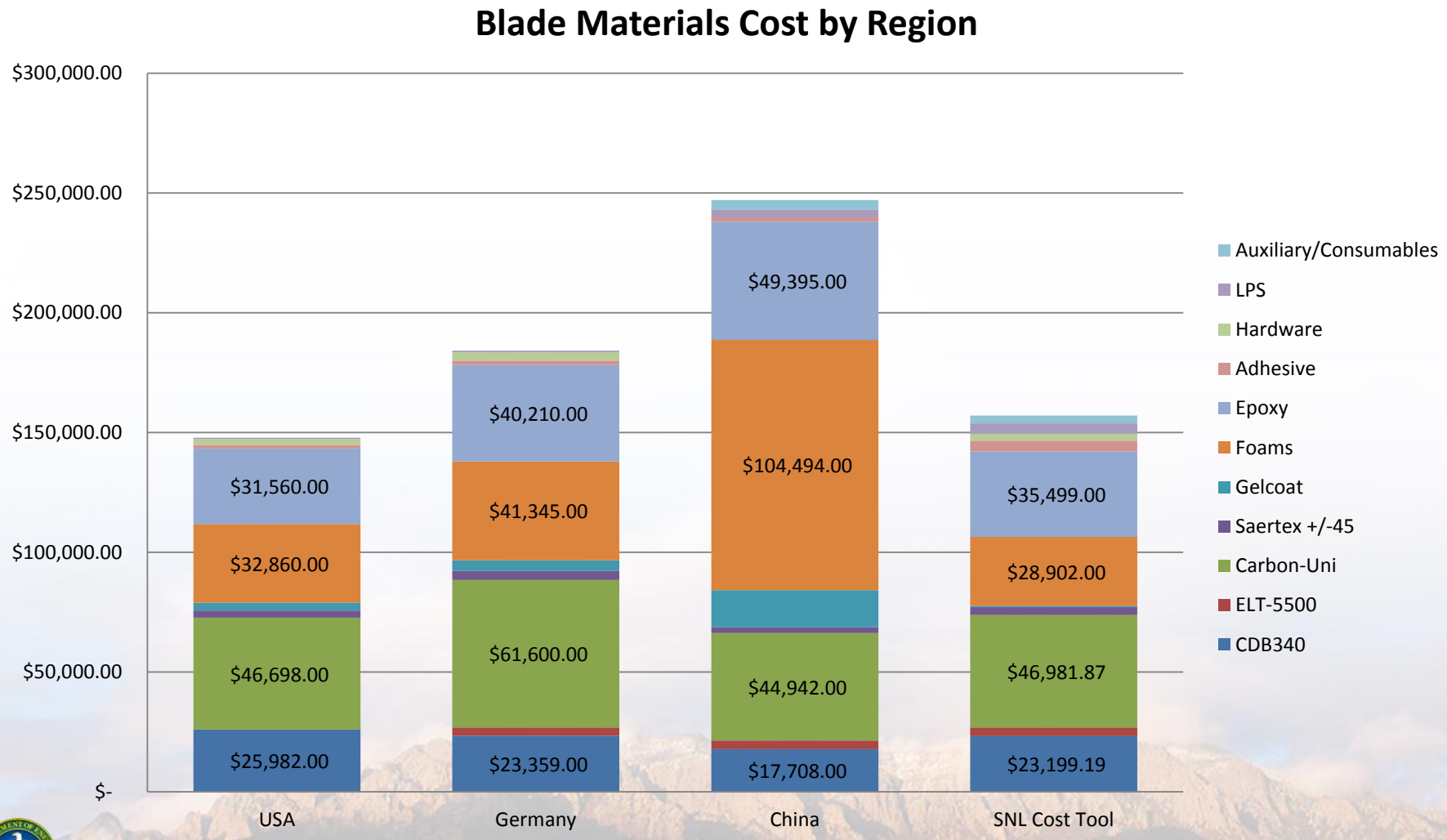
Additional Functions / Features

- **SNL materials library**
- **Adaptable to custom manufacturing process steps**
  - labor40_xls2mat.m
  - update or define custom steps in excel
- **Accepts many cost data input types**
  - cost in \$/lb, \$/m^2, etc.
  - resin infusion by vol. fraction, areal spread
- **< ¼ second CPU time**
- **extensive error handling**

Model Validation

- **many points of reference**
- **shown here: GLWN Manufacturing Competitiveness Study**
  - 5MW
  - 61.5m
  - design from SNL/NREL
  - data from 8 factories in different regions
  - 3 from USA manufacturers

Model Validation



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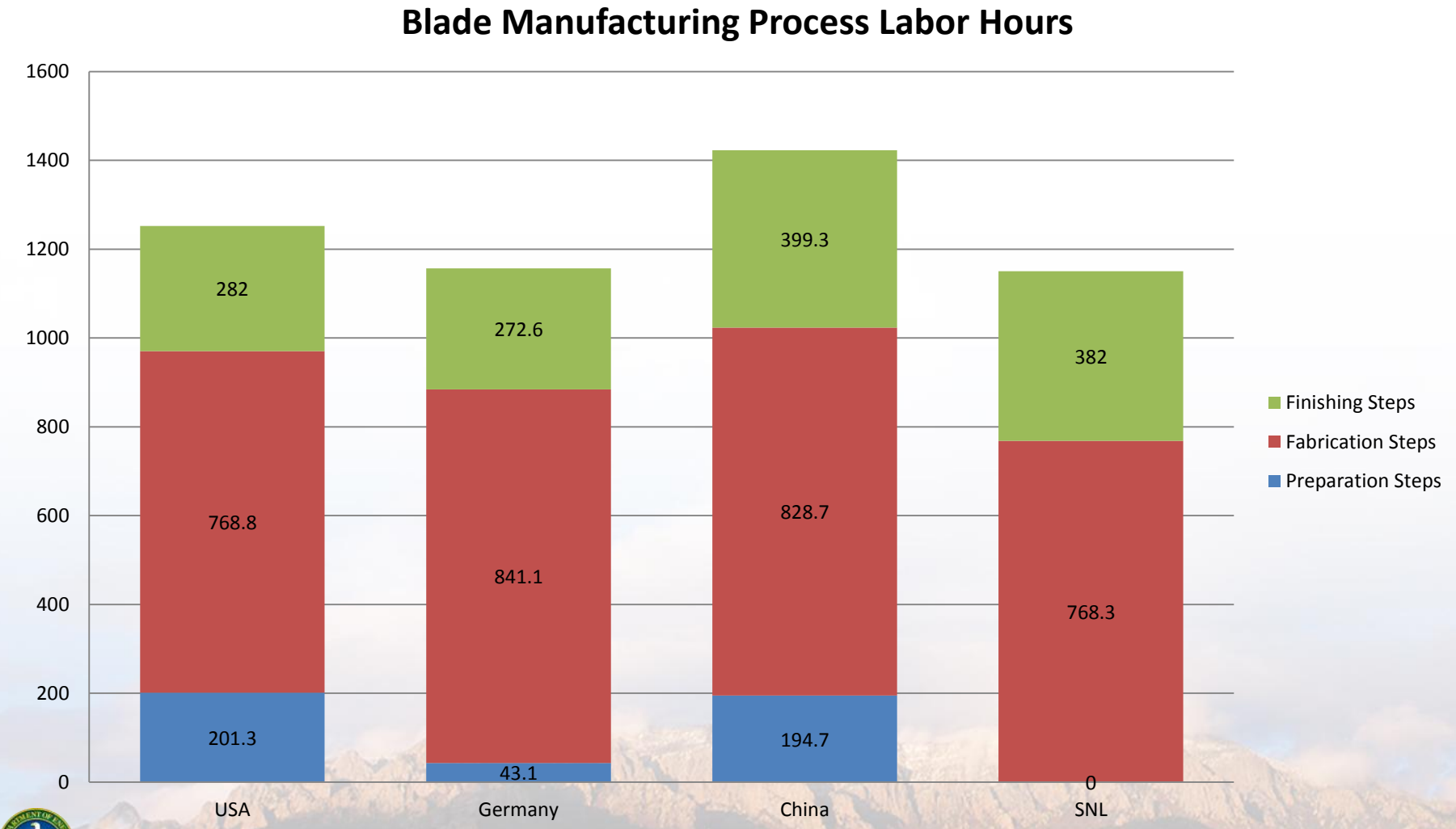
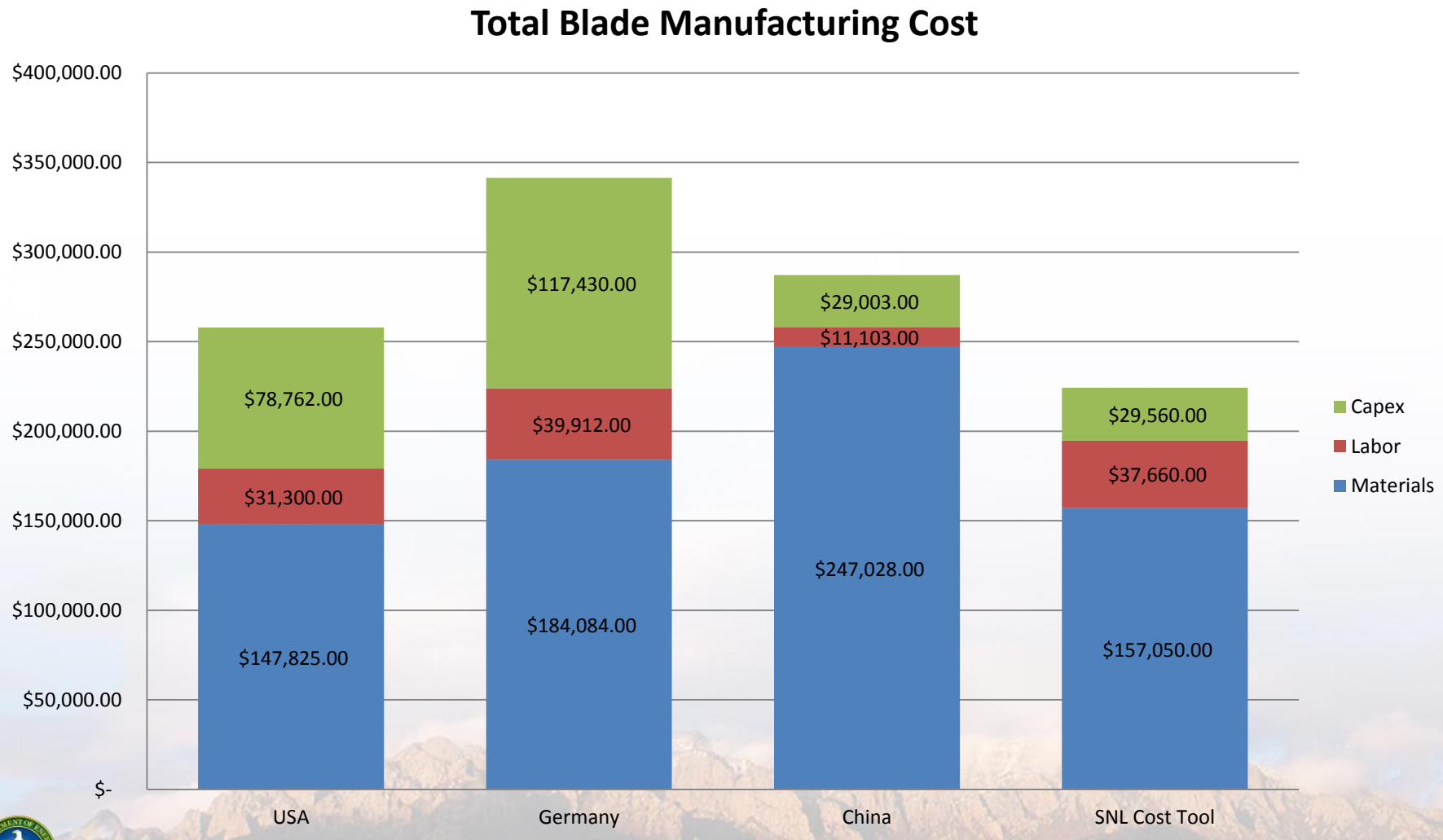
Model Validation



Model Validation



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Parametric Analysis

- **61.5m carbon spar blade**
- **single-parameter variation: carbon cost**

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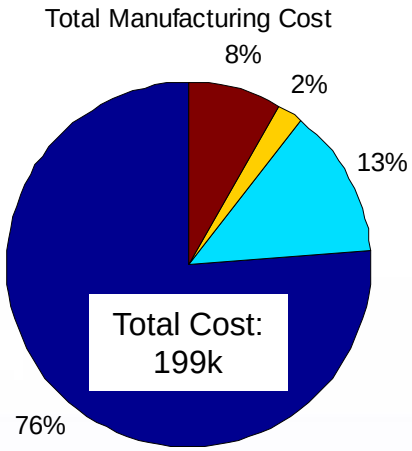
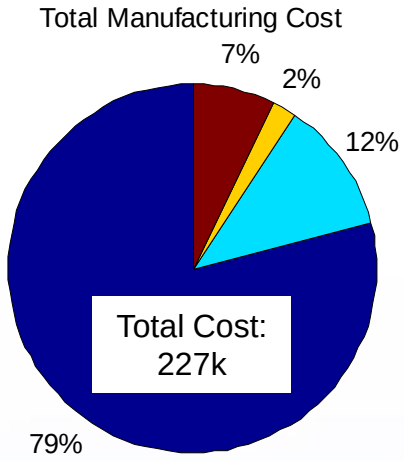
Parametric Analysis

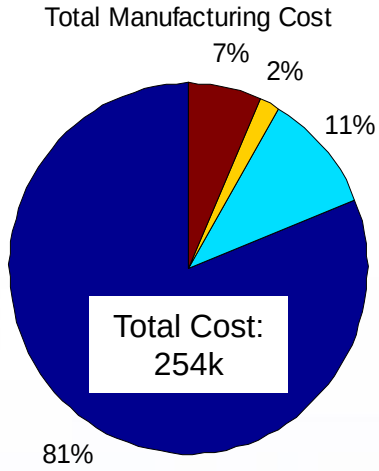
20$/kg

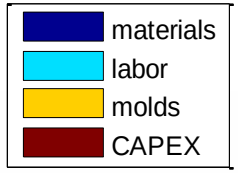


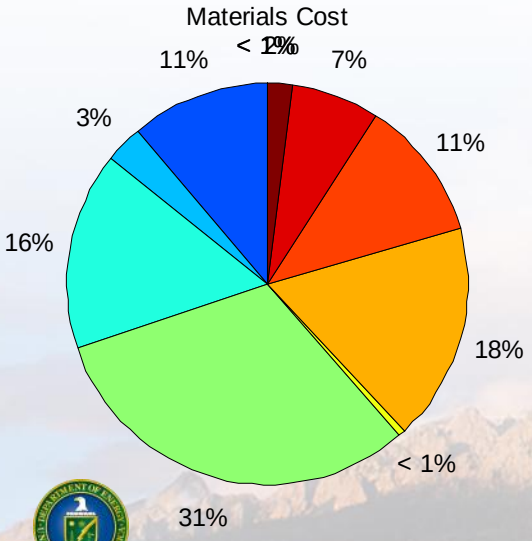
30$/kg

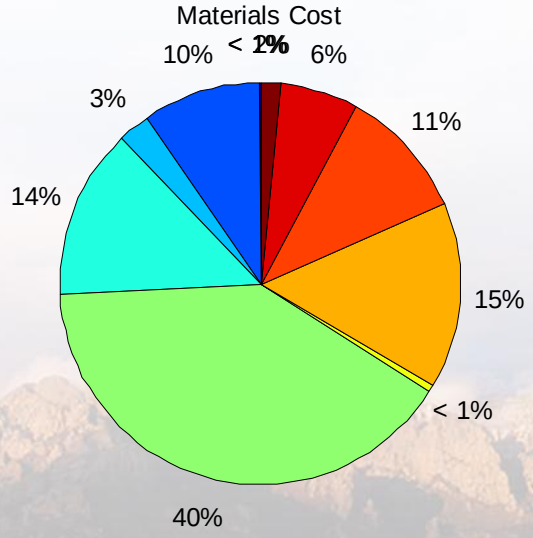


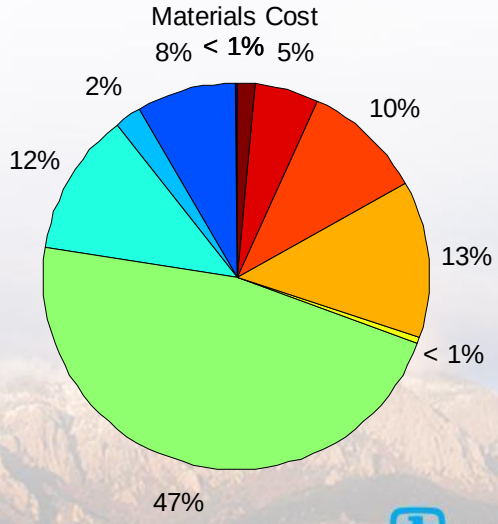
40$/kg

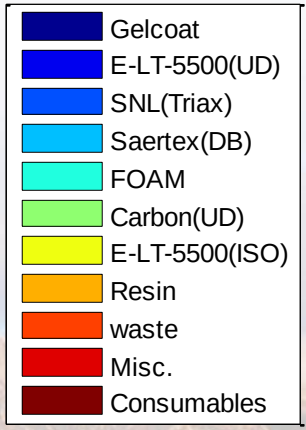












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Future Work

- **Optimization**
  - What do optimal blades look like when we optimize for cost?
  - Tip Speed Study blades
  - High-Modulus Carbon Fiber (properties-cost tradeoffs)
  - Bio-based materials
- **CAPEX/Factory Model**
- **Integration with AEP tool**

Acknowledgements

- Mentor: Brian Naughton
- Design Codes: Jon Berg
- NRT: Brian Resor
- Supervisor: Dave Minster

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Thank You

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