CHANGING WHAT'S POSSIBLE

Introduction to Cost Modeling, Template Overview

for Performers

ARPA-E Tech-to-Market

February 12, 2014

Outline

- Context for Cost Modeling
  - Motivation, Definitions, and Examples
- Template Description
  - Scope, Overview, Worksheet Details
- Final Remarks

Part I

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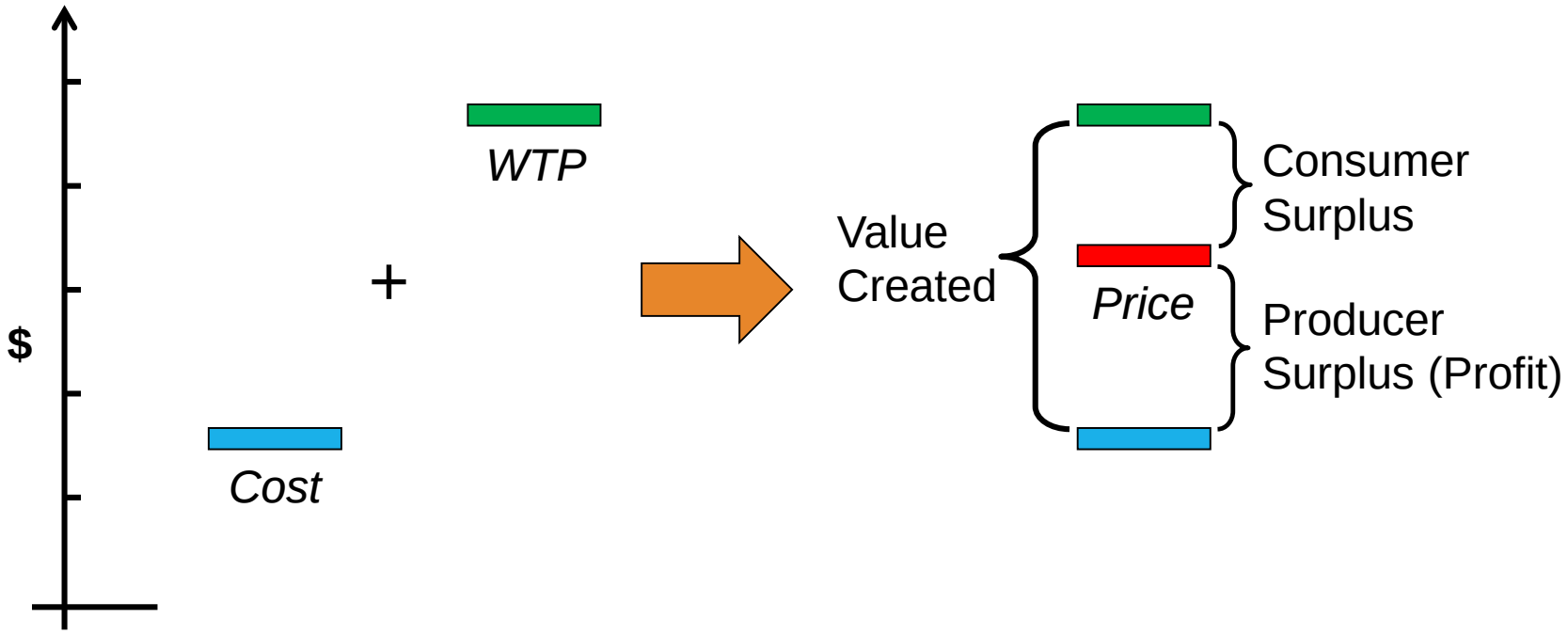
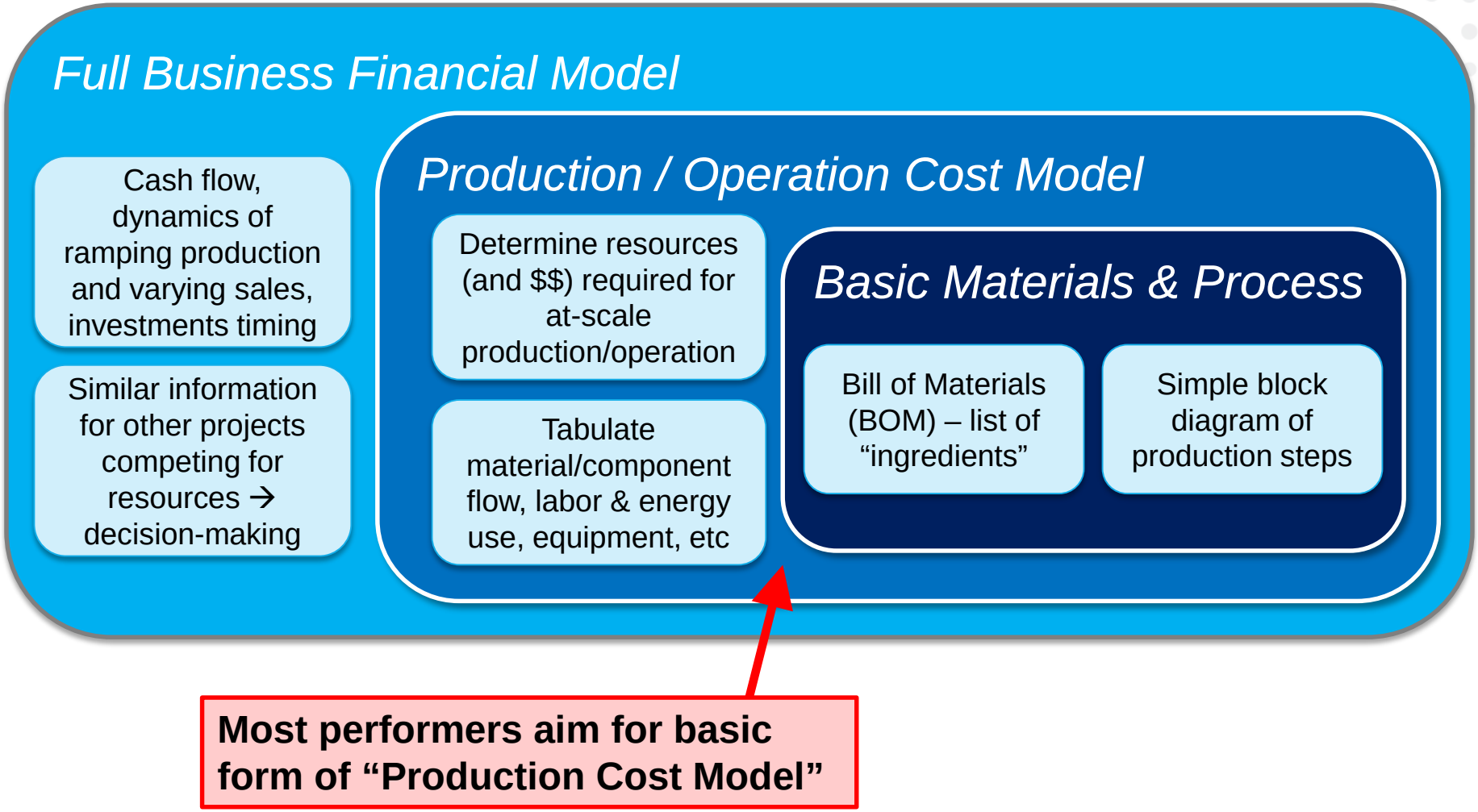
Cost & Value

- *Production cost* (necessary but not sufficient by itself)
  - + *Willingness to pay* (customer value)
    - → *Value creation* potential of product



Economic Modeling for Technology



Most performers aim for basic form of "Production Cost Model"

Cost Modeling Enables Research & Development

- Integrates calculations together for holistic consideration

- Identify cost drivers → steer research

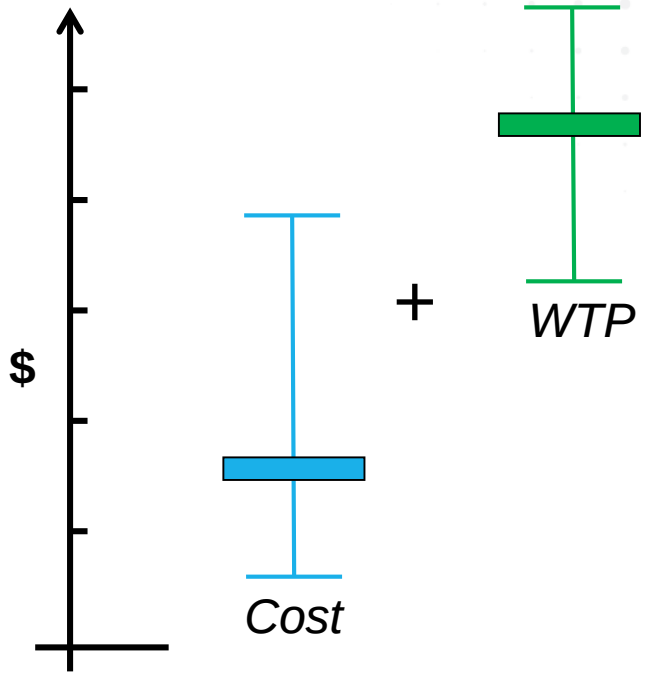
- Communicate results with stakeholders
  - Internal: *R&D*, *Management*, *Marketing*
  - External: *Industry Advisors, Investors*, *Customers*, *Licensing Partners*

Modeling Benefits, Despite Uncertainty

- Possible concern:

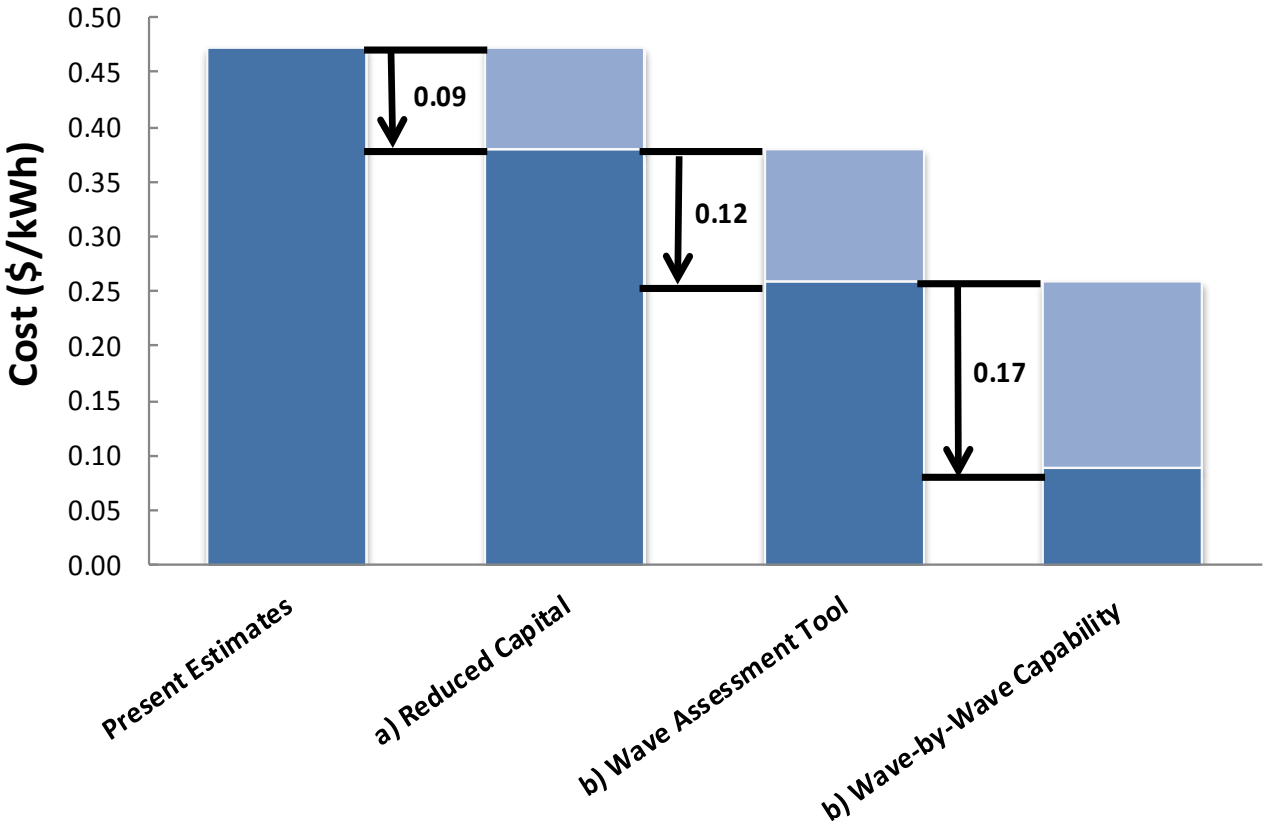
"It's too early—there is too much uncertainty to calculate exactly how profitable this company/product would be."

- Modeling still beneficial:
  - Make uncertainties explicit
  - Identify most valuable improvements
  - Develop targets, metrics
  - Bound with theoretical limits
  - Create thought framework for reducing uncertainties



Example Techno-Economic Analysis

- Wave Energy Converters



(Courtesy of Sea Engineering, Inc.)

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Template Scope

MODEL INCLUDES
All major cost factors for production of saleable product
Production model for bottom-up calculation of labor, material, and capital requirements to meet production volume
Cost sensitivity and scaling analyses
Estimated value of production project using sale price

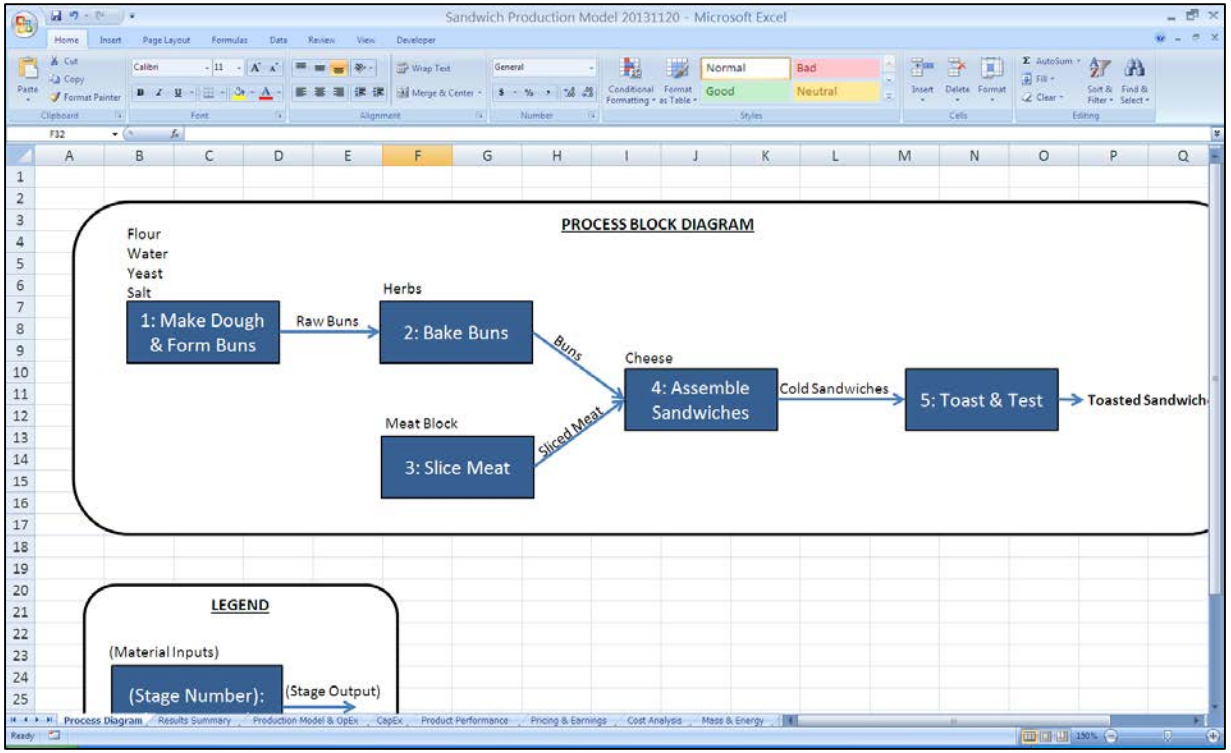
MODEL DOES NOT INCLUDE
Operational details (e.g. schedule of work shifts)
Minute product details
Growth dynamics of business, production, or sales
Company financial model (debt, equity, taxes, etc.)

Template Worksheets

#	Sheet Name	Description
1	**Process Diagram**	“Hand-drawn” block diagram
2	**Results Summary**	Displays key model inputs, outputs, essential analysis
3	**Production Model & OpEx**	Step-by-step calculations: materials, labor, and production requirements (core of whole spreadsheet)
4	**CapEx**	Building, equipment, tools, etc.
5	**Product Performance**	Performance metrics, tied to production model if possible, supporting product value to customer
6	**Financial**	“Fully loaded” product cost, price, margin, payback period
7	**Cost Analysis**	Sensitivity analysis, step-by-step breakdown, scaling
8	**Mass & Energy**	Supporting calculations regarding materials and processes

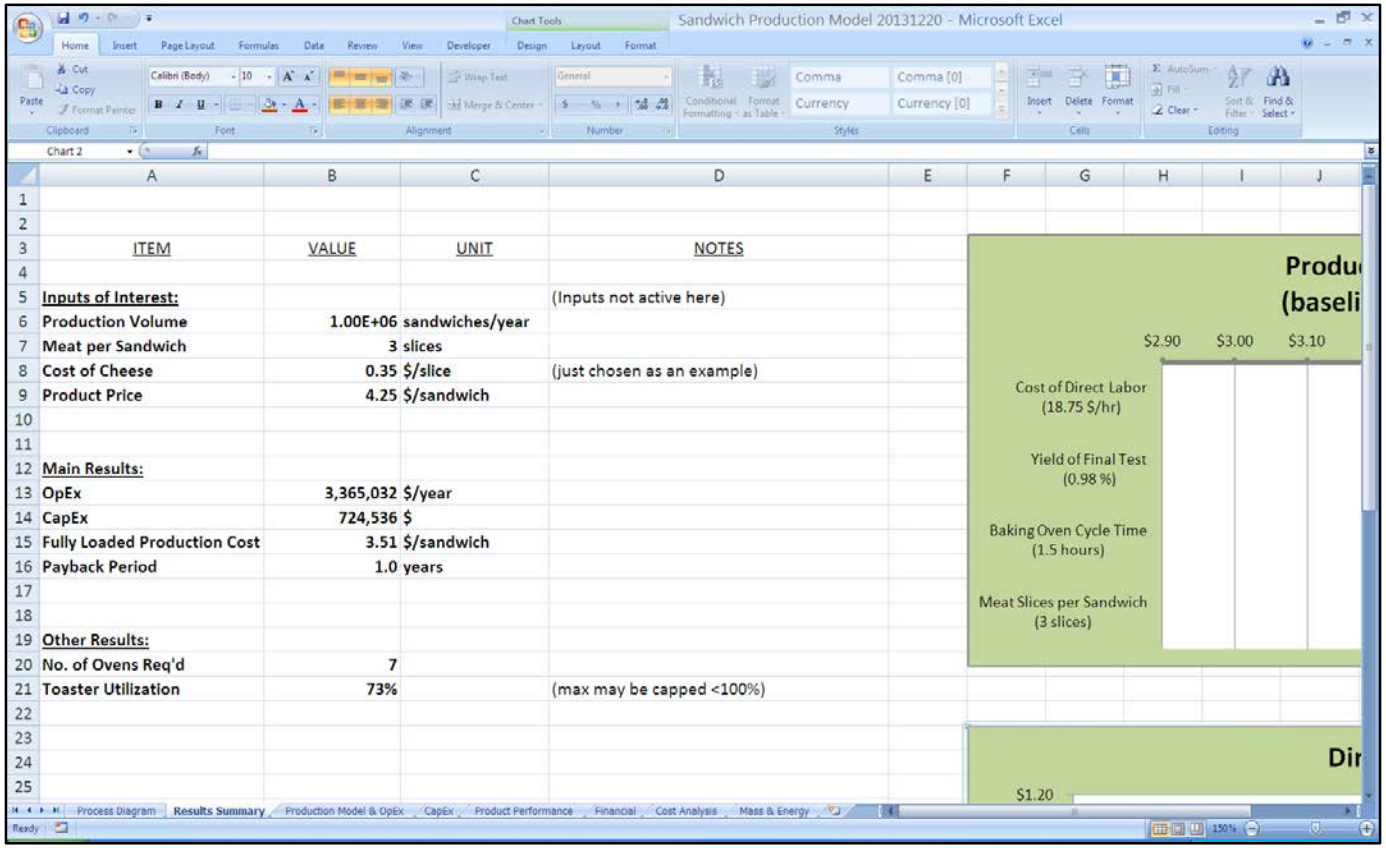
Sheet 1: Process Diagram

- **Capture the entire production process in easily understood format**
  - Descriptive step names and step-wise material inputs and outputs
  - Establish modeling level of detail: each step to receive its own treatment in production model
  - Overall inputs and output define position in value chain



Sheet 2: Results Summary

- Provides a quick-look at key model inputs and outputs
  - May choose to link inputs from this page to quickly run and show multiple scenarios



	A	B	C	D
1				
2				
3	ITEM	VALUE	UNIT	NOTES
4				
5	Inputs of Interest:			(Inputs not active here)
6	Production Volume	1.00E+06	sandwiches/year	
7	Meat per Sandwich	3	slices	
8	Cost of Cheese	0.35	$/slice	(just chosen as an example)
9	Product Price	4.25	$/sandwich	
10				
11				
12	Main Results:			
13	OpEx	3,365,032	$/year	
14	CapEx	724,536	$	
15	Fully Loaded Production Cost	3.51	$/sandwich	
16	Payback Period	1.0	years	
17				
18				
19	Other Results:			
20	No. of Ovens Req'd	7		
21	Toaster Utilization	73%		(max may be capped <100%)
22				
23				
24				
25				

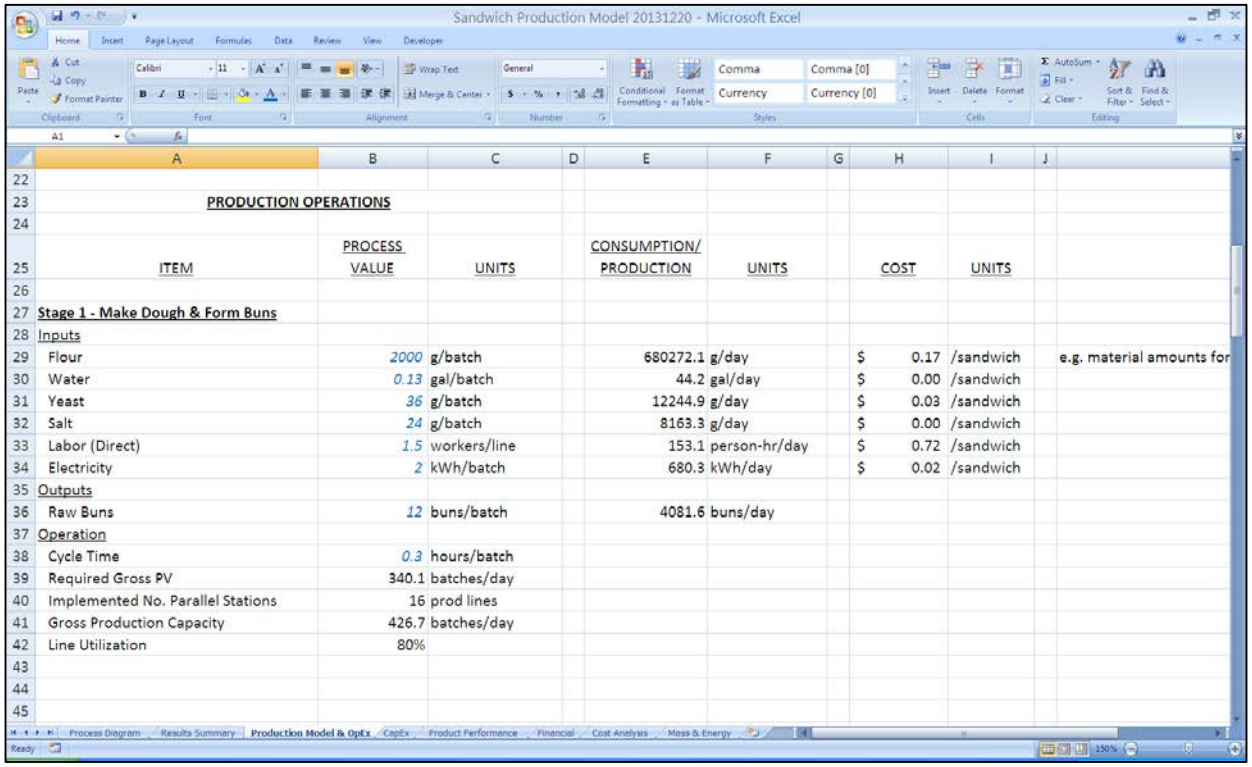
Sheet 3: Production Model & OpEx (1/3)

- **Builds up quantitative operating requirements for reaching desired production volume**
  - Calculate backwards: [*production volume*] → [*throughput of last step*] → [*throughput of second-to-last step*] →…→ [*throughput of first step*]
  - Requires definition of:
    - Process-Step Properties: *Batch Size*; *Cycle Time*; *Usage of Labor*, *Materials*, *Utilities*; *Yield*, etc.
    - Operational Availability: *Days per Year*, etc.

- **Tabulates consumption and production**
  - Materials/Components, Labor, Utilities, Product
  - Calculates and implements required parallel production stations, step-wise
  - Using cost rates, calculates all operating expenses

Sheet 3: Production Model & OpEx (2/3)

- **Batch definition grants flexibility**
  - Allows realistic, convenient units and conversion of units during steps
    - Units must match between steps; convert units from input to output within a step
  - For continuous process: maintain proportions, absolute values of materials and time can be arbitrarily small as needed



	A	B	C	D	E	F	G	H	I	J
22										
23	PRODUCTION OPERATIONS									
24										
25	ITEM	PROCESS VALUE	UNITS		CONSUMPTION/ PRODUCTION	UNITS		COST	UNITS	
26										
27	Stage 1 - Make Dough & Form Buns									
28	Inputs									
29	Flour	2000	g/batch		680272.1	g/day		$ 0.17	/sandwich	e.g. material amounts for
30	Water	0.13	gal/batch		44.2	gal/day		$ 0.00	/sandwich	
31	Yeast	36	g/batch		12244.9	g/day		$ 0.03	/sandwich	
32	Salt	24	g/batch		8163.3	g/day		$ 0.00	/sandwich	
33	Labor (Direct)	1.5	workers/line		153.1	person-hr/day		$ 0.72	/sandwich	
34	Electricity	2	kWh/batch		680.3	kWh/day		$ 0.02	/sandwich	
35	Outputs									
36	Raw Buns	12	buns/batch		4081.6	buns/day				
37	Operation									
38	Cycle Time	0.3	hours/batch							
39	Required Gross PV	340.1	batches/day							
40	Implemented No. Parallel Stations	16	prod lines							
41	Gross Production Capacity	426.7	batches/day							
42	Line Utilization	80%								
43										
44										
45										

Sheet 3: Production Model & OpEx (3/3)

(1) Step-wise Required Gross Production Volume

$$GPV_i = GPV_{i+1} \times \frac{1}{Y_i} \times \left[\frac{(\text{Batch Input Quantity})_{i+1}}{(\text{Batch Output Quantity})_i} \right]$$

- GPV_i: batches per day (step *i*)
- GPV_{i+1}: batches per day (step *i+1*)
- Y_i: Y: Yield (e.g. 98%)
- $\frac{(\text{Batch Input Quantity})_{i+1}}{(\text{Batch Output Quantity})_i}$: batch size conversion factor (must be same units)

(2) Parallel Production Required

$$(\text{Min Req'd Prod Lines})_i = \frac{GPV_i}{\left[\frac{\left(\frac{\text{Operating Hours}}{\text{Operating Day}} \right)}{\left(\frac{\text{Hours}}{\text{Batch}} \right)_i} \right]} \times \frac{1}{Util_{MAX}}$$

- $\left(\frac{\text{Hours}}{\text{Batch}} \right)_i$: batches per day per line
- $Util_{MAX}$: maximum allowed utilization (e.g. 85%)

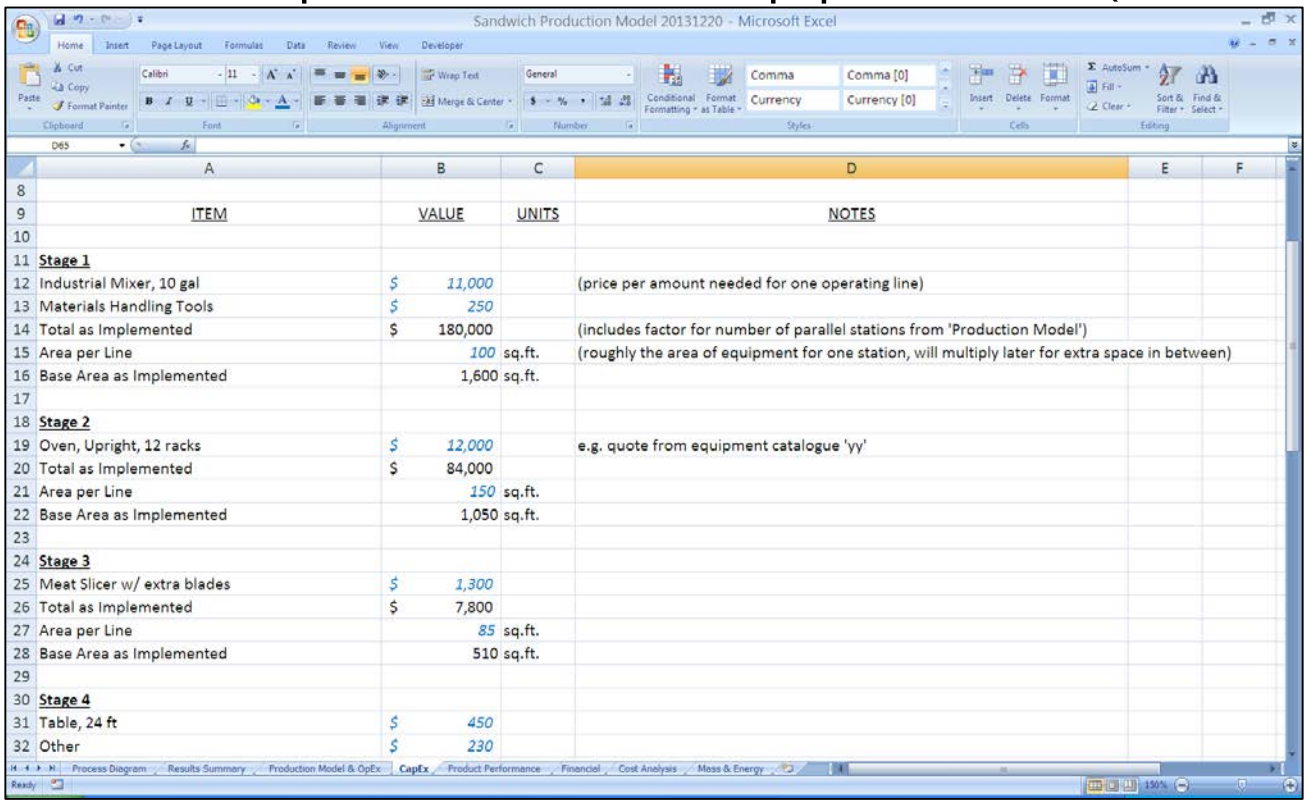
(3) Labor Required

$$\text{Direct Labor} = \frac{\text{Workers}}{\text{Line}} \times \#\text{Lines} \times \frac{\text{Operating Hours}}{\text{Operating Day}} \times \text{Utilization}$$

(person-hrs/day)

Sheet 4: CapEx

- **Calculate capital expenditures**
  - Equipment/machinery/tooling totals from per item price and number of stations
  - Estimated floor space needed from equipment sizes (rent is in OpEx)

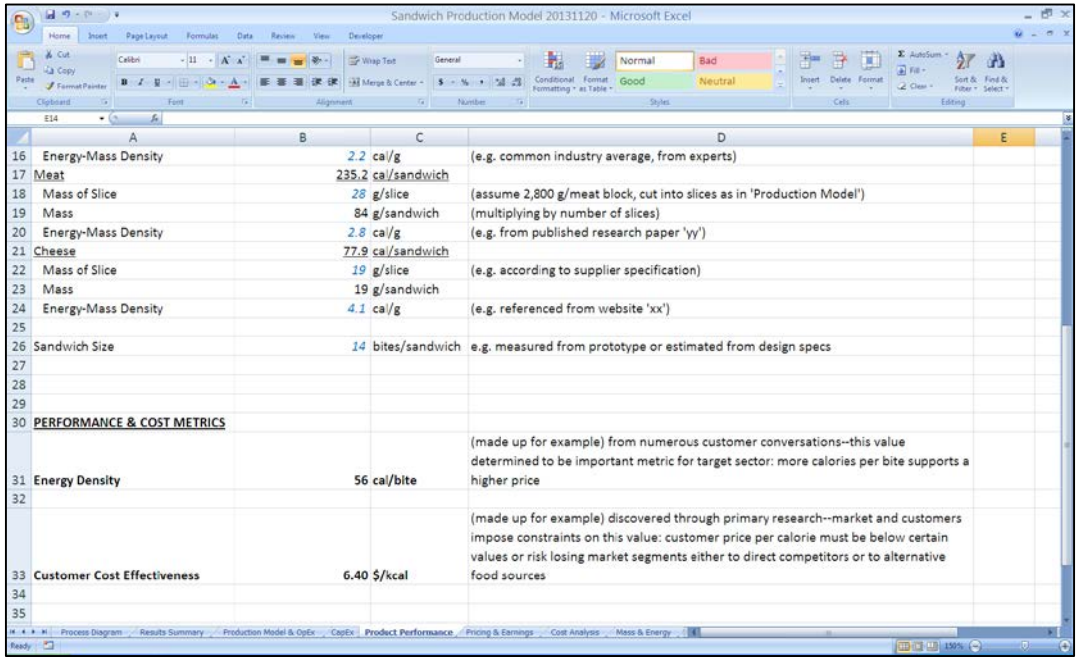


Sandwich Production Model 20131220 - Microsoft Excel

	A	B	C	D
8				
9	ITEM	VALUE	UNITS	NOTES
10				
11	**Stage 1**			
12	Industrial Mixer, 10 gal	$ 11,000		(price per amount needed for one operating line)
13	Materials Handling Tools	$ 250		
14	Total as Implemented	$ 180,000		(includes factor for number of parallel stations from 'Production Model')
15	Area per Line	100	sq.ft.	(roughly the area of equipment for one station, will multiply later for extra space in between)
16	Base Area as Implemented	1,600	sq.ft.	
17				
18	**Stage 2**			
19	Oven, Upright, 12 racks	$ 12,000		e.g. quote from equipment catalogue 'yy'
20	Total as Implemented	$ 84,000		
21	Area per Line	150	sq.ft.	
22	Base Area as Implemented	1,050	sq.ft.	
23				
24	**Stage 3**			
25	Meat Slicer w/ extra blades	$ 1,300		
26	Total as Implemented	$ 7,800		
27	Area per Line	85	sq.ft.	
28	Base Area as Implemented	510	sq.ft.	
29				
30	**Stage 4**			
31	Table, 24 ft	$ 450		
32	Other	$ 230		

Sheet 5: Product Performance

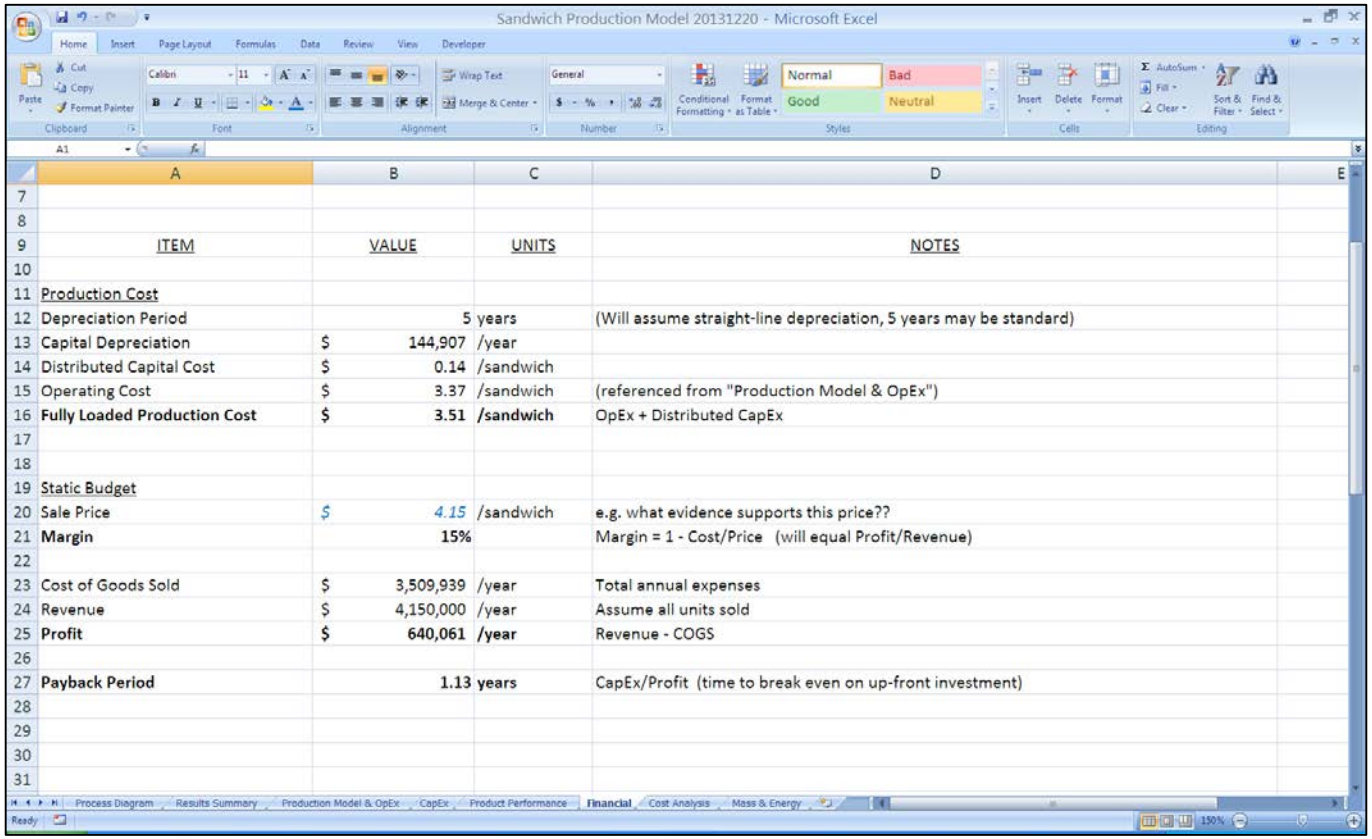
- **Calculate/capture quantitative performance metrics**
  - Tied to production model if possible
  - Metrics selected based on customer needs and segmentation of market → supports target price and production volume
  - May expand sheet to model product operation → estimate value, willingness to pay



	A	B	C	D	E
16	Energy-Mass Density	2.2	cal/g	(e.g. common industry average, from experts)	
17	Meat	235.2	cal/sandwich		
18	Mass of Slice	28	g/slice	(assume 2,800 g/meat block, cut into slices as in 'Production Model')	
19	Mass	84	g/sandwich	(multiplying by number of slices)	
20	Energy-Mass Density	2.8	cal/g	(e.g. from published research paper 'yy')	
21	Cheese	77.9	cal/sandwich		
22	Mass of Slice	19	g/slice	(e.g. according to supplier specification)	
23	Mass	19	g/sandwich		
24	Energy-Mass Density	4.1	cal/g	(e.g. referenced from website 'xx')	
25					
26	Sandwich Size	14	bites/sandwich	e.g. measured from prototype or estimated from design specs	
27					
28					
29					
30	PERFORMANCE & COST METRICS				
31	**Energy Density**	**56**	**cal/bite**	(made up for example) from numerous customer conversations--this value determined to be important metric for target sector: more calories per bite supports a higher price	
32					
33	**Customer Cost Effectiveness**	**6.40**	**$/kcal**	(made up for example) discovered through primary research--market and customers impose constraints on this value: customer price per calorie must be below certain values or risk losing market segments either to direct competitors or to alternative food sources	
34					
35					

Sheet 6: Financial

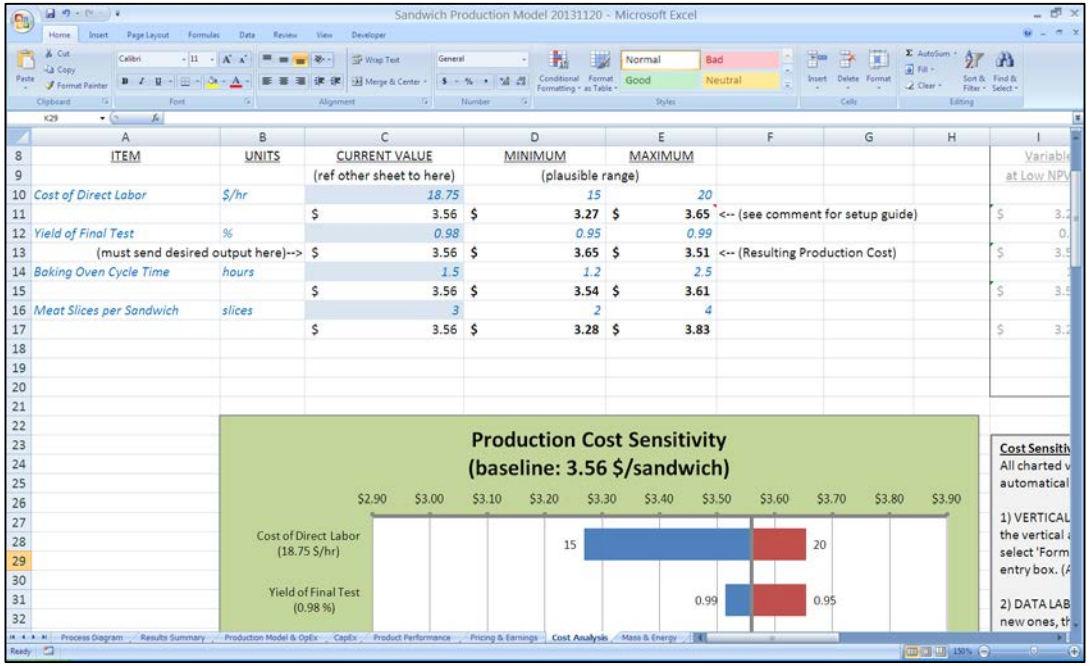
- **Production project value calculation**
  - Capital Depreciation + OpEx → "Fully Loaded" Unit Production Cost
  - Price, Margin → Revenue → Profit → Payback Period



	A	B	C	D	E
7					
8					
9	ITEM	VALUE	UNITS	NOTES	
10					
11	Production Cost				
12	Depreciation Period	5	years	(Will assume straight-line depreciation, 5 years may be standard)	
13	Capital Depreciation	$ 144,907	/year		
14	Distributed Capital Cost	$ 0.14	/sandwich		
15	Operating Cost	$ 3.37	/sandwich	(referenced from "Production Model & OpEx")	
16	**Fully Loaded Production Cost**	**$ 3.51**	**/sandwich**	OpEx + Distributed CapEx	
17					
18					
19	Static Budget				
20	Sale Price	*$ 4.15*	/sandwich	e.g. what evidence supports this price??	
21	**Margin**	**15%**		Margin = 1 - Cost/Price (will equal Profit/Revenue)	
22					
23	Cost of Goods Sold	$ 3,509,939	/year	Total annual expenses	
24	Revenue	$ 4,150,000	/year	Assume all units sold	
25	**Profit**	**$ 640,061**	**/year**	Revenue - COGS	
26					
27	**Payback Period**	**1.13**	**years**	CapEx/Profit (time to break even on up-front investment)	
28					
29					
30					
31					

Sheet 7: Cost Analysis

- **A closer look at cost factors and uncertainties**
  - Single-variable sensitivity analysis: automatically calculate and display changes in fully loaded cost due to variation in model input variables
  - Scaling of unit cost with production volume (including automatic re-calculation of OpEx and CapEx based on production requirements)
  - Cost breakdown by production step and resource category



Sheet 8: Mass & Energy

- **Calculations to provide or support values used in production model or product performance**
  - e.g. balancing chemical equations, thermodynamics, part count/mass derivation
  - Housing calculations here maintains focus and clarity in other sheets
  - (not populated in template)

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Final Remarks

- Get started modeling cost early, and refine as knowledge advances
  - guess as placeholder to get framework in place (and make note of it)
  - work on larger factors first (getting first significant digit right is a challenge)
- Use, manipulate, and adapt the template spreadsheet to suit your needs, but
  - be guided by its scope (deliberate)
  - don't dodge necessary considerations because of difficulty to validate or seemingly unfavorable results
- Full business financial model (cash flow, debt, timing, etc.) also needed before pitching for external financing (not shown here)
- Send any cost modeling questions & comments to your ARPA-E Tech-to-Market Advisor

END

Appendix: Matching Uncertainties (old)

Increasing Technology Readiness Level

Data Inputs	Small-scale experimental data / conceptual prototype	Small-scale process unit data / "Minimum Viable Product"	Pilot plant data / Scale Product	Demonstration scale data / For Sale Production
Process Model	Block Flow Diagram / Bill of Materials	Process Flow Diagram / BOM + rough scematic	Process Simulation / Computer Aided Design	Simulation verified with operating data / Detailed CAD
Price Inputs	Published prices, estimates based on similar products / processes	Vendor discussions to inform major costs, estimates on others	Vendor quotes for most equipment	Negotiated contract data
Level of Detail	Major cost drivers only	Estimates of majority of operating costs and capital equipment	90% of equipment and operating costs included as a line item	98% included and verified by an independent 3rd party
Capital Costing	Recognizing that it will have a required return	"Rule of 72" - 10% discount rate	Discount rate based on variability of free cash flow with market	Full Weighted Average Cost of Capital with all Tax Shields included
Approximate effort	40 man-hours	200 man-hours	2,000 man-hours	5,000+ man-hours
Review/Input	Co-Worker Review	Several co-workers from varying disciplines	Input from a potential investor under a NDA	Fully shared with EPC and bank, open to modification/scrutiny
Cost Model Use	Focusing Research and Development Effort	Developing research targets/goals	Understanding long-term viability of the technology, pitching VC's	Securing Bank Financing, projecting earnings, activity-based costing