HOW TO BUILD A GOOD COST MODEL

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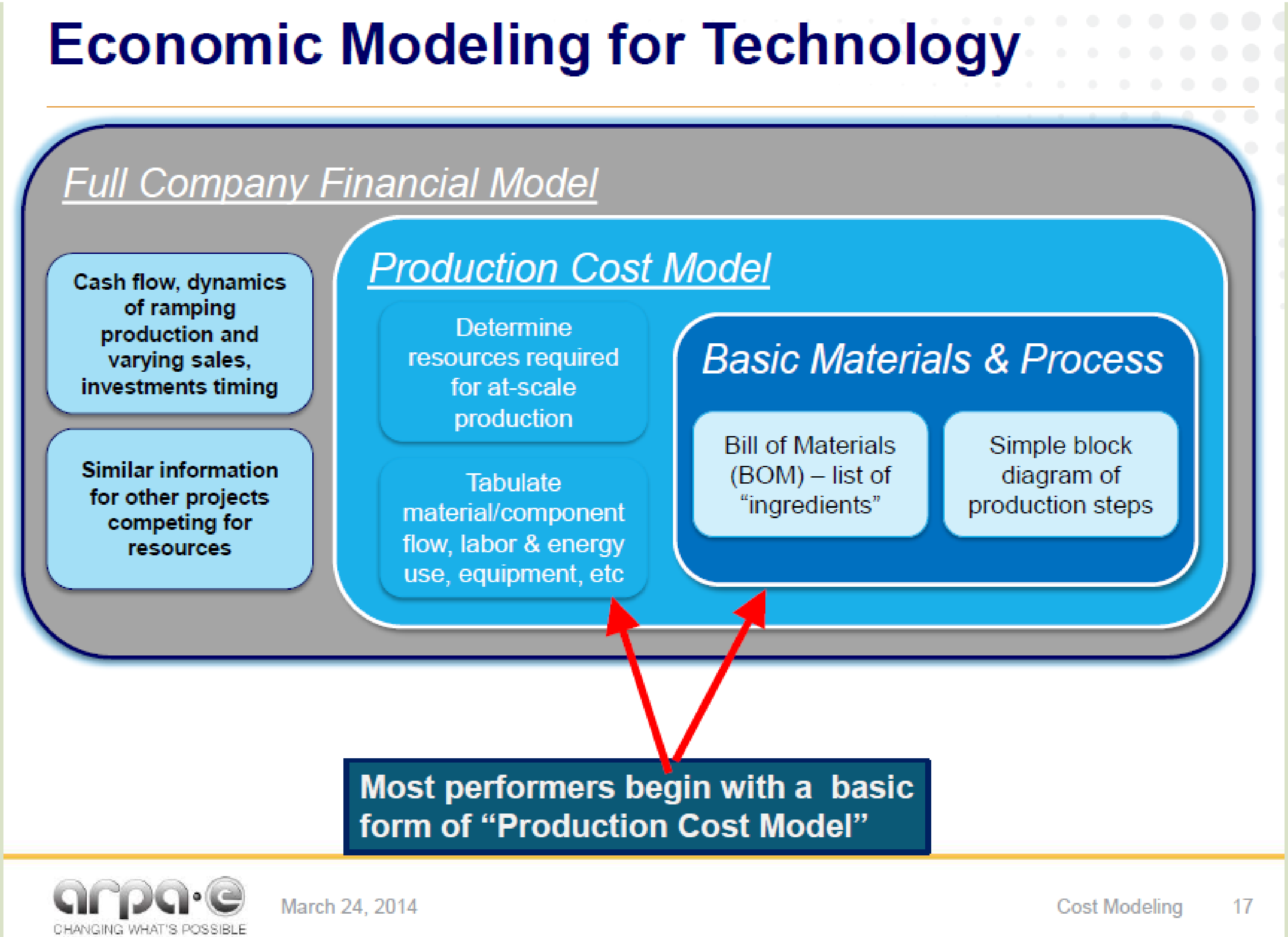
AGENDA

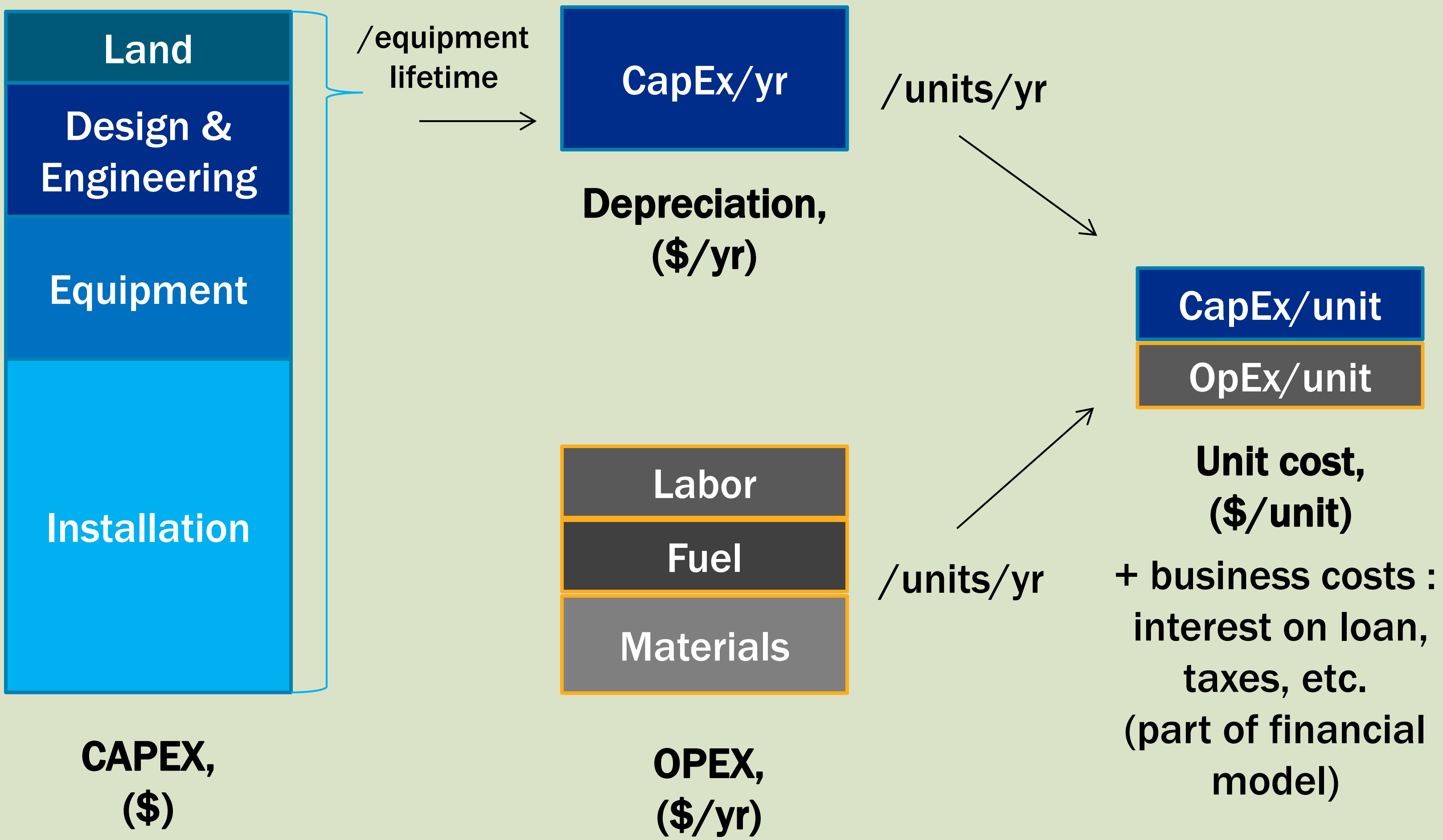
- Bottom line numbers – CapEx, OpEx, $/unit
- Characteristics of a user-friendly model
- Data scavenger hunting tips
- Cost estimating tips
- Scenario modeling

MODEL HEIRARCHY



Sue Babinec, ARPA-e "Tech to Market" presentation

PRODUCTION COST MODEL BOTTOM-LINE NUMBERS

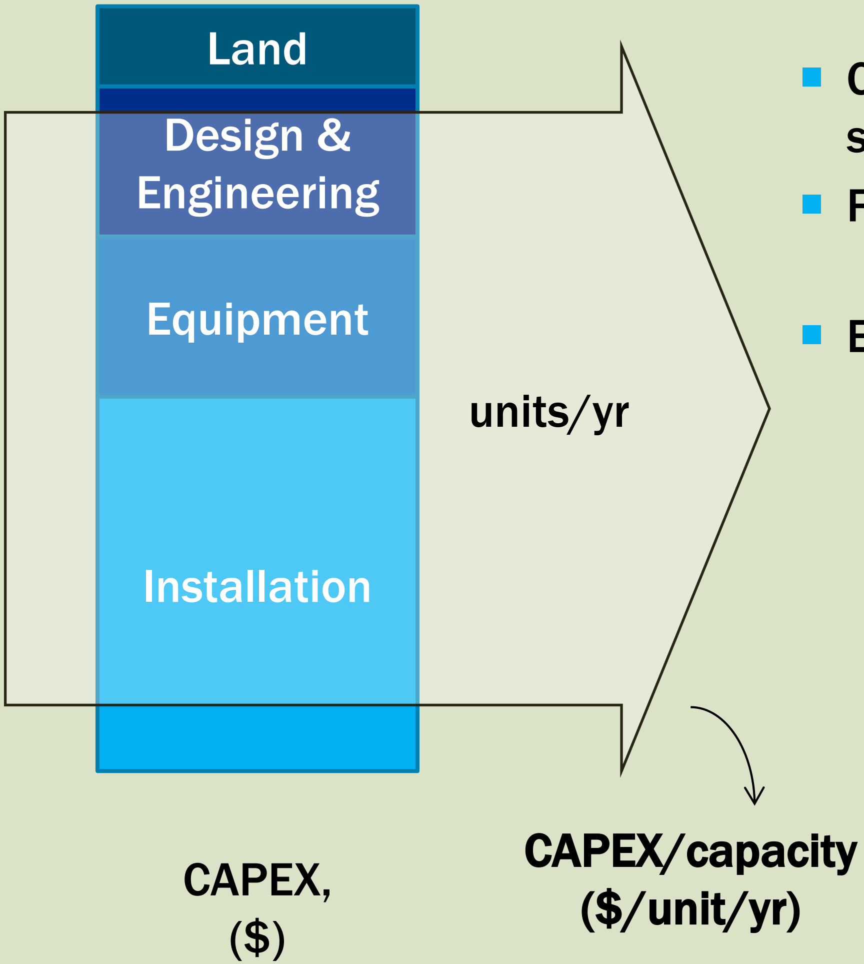


Also known as: capital expenditure, capital cost, investment cost, upfront cost

Also known as: operating expenditure, operating cost

Hypothetical factory, simplified cost structure

CAPEX OVER CAPACITY: FOR COMMODITIES



- Comparing options for producing same thing
- Rated output basis
  - nameplate capacity
- Examples:
  - $/kW
  - $/MGY (million gallons per year)

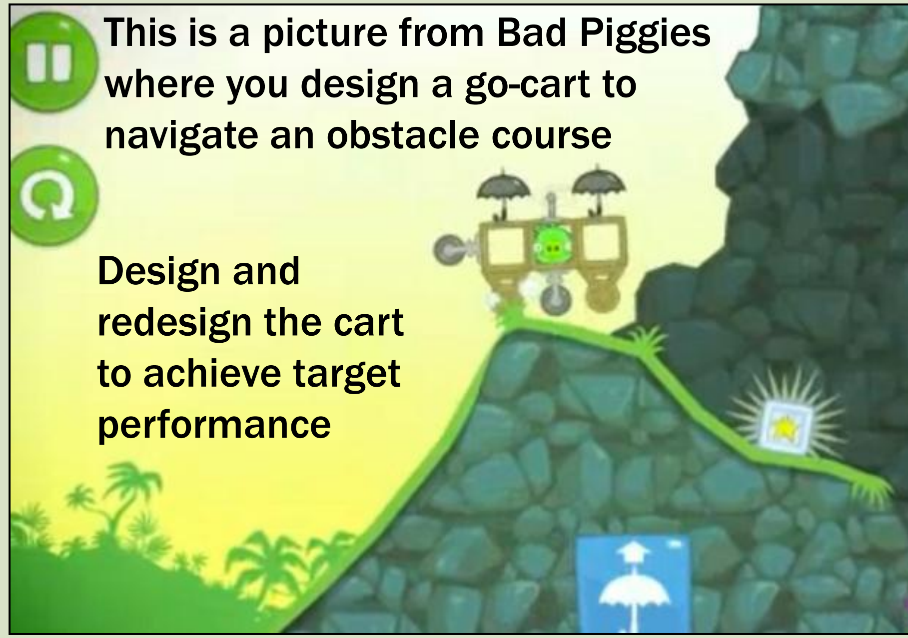
IMPLICATIONS OF BOTTOM LINE NUMBERS

- Throughput Rate is key
  - 24/7 operation
  - "capacity factor"
    = actual/potential output
    80-95% for commercial,
    less for pilot plant
  - Know your rate limiting step!
  - Include realistic downtime

- CapEx is more important than OpEx
  - Time value of $:
    - CapEx is now
    - OpEx is in future and prices less certain
  - So… Focus on lowering your CapEx first

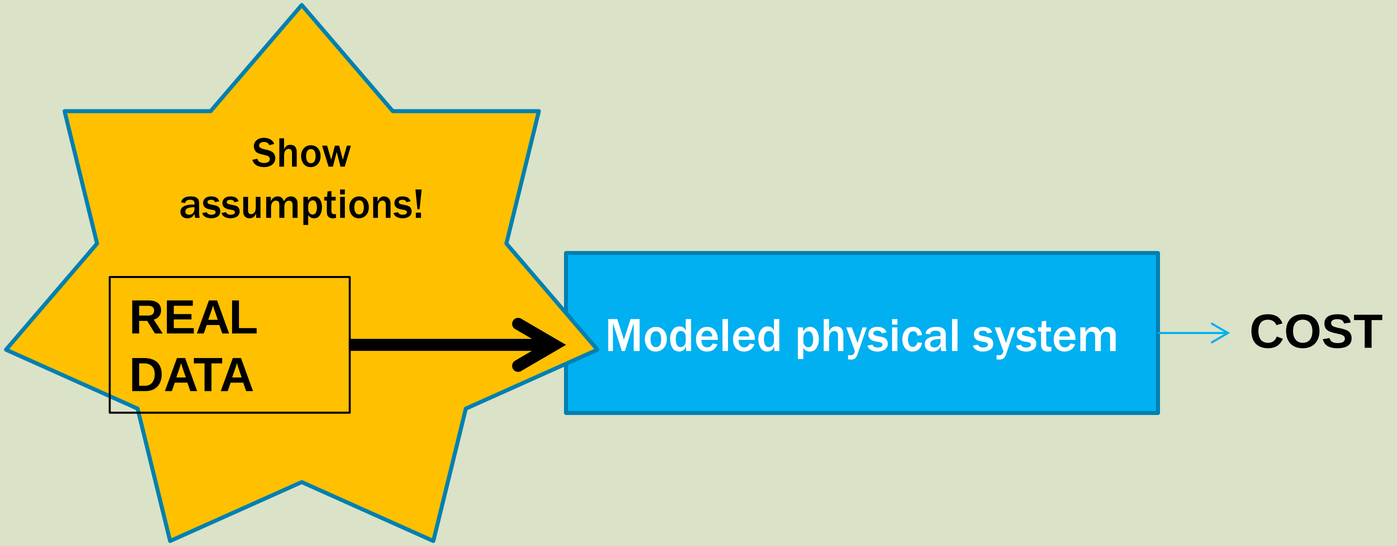
YOUR MODEL CAN BE A TOOL FOR DECISION MAKING

- To be a tool
  - Unknowns are variables
  - Physical system drives results
  - “What if”
  - High interdependency of parameters



- To drive decisions
  - R&D effort is linked to cost drivers
  - Sensitivities are known
  - Actual, target, theoretical values defined
  - Brutally honest

DEFEAT SKEPTICISM: SHOW YOUR ASSUMPTIONS



WHY YOUR MODEL SHOULD BE USER-FRIENDLY

- For yourself

- For your team
  - Everyone understands cost drivers

- Investors and partner due diligence
  - Confusion → skepticism
  - Visible logic → confidence

- Model complexity will grow, then shrink
  - As real numbers replace calculations
  - Streamlined as you weed out noise

STRUCTURE THE MODEL SO ITS EASY TO FOLLOW

- Diagrams (make them)
  - Process flow diagrams
  - Device diagrams

- On separate tabs
  - Physical system parameters
  - Capital cost
  - Operating cost
  - Summary page: key inputs/outputs, financial assumptions

Summary
CAPEX
OPEX
Physical (non-cost)
Physical (non-cost)

- Calculations
  - Clarify what numbers are inputs vs. calculated (color key)
  - Easy to read : 220,000 vs 224531.692
  - Show units everywhere
  - Disaggregate calculations (show intermediate values) to avoid complex formulas, which are hard to follow
  - Name your variables for easy formula reading

- Comments (use them)

CAPEX ESTIMATION

- **Installed cost**
  - Generally ~3-5 times the cost of equipment and materials
  - "Lang factor" in chem eng used as multiplier
  - Can be much higher for pilot scale

- **Scale factors**
  - Use to estimate equipment cost by physical comparison

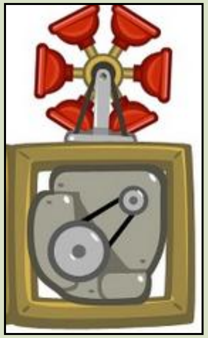
    $\text{Cost B} = \text{Cost A} * (\text{Output B}/\text{Output A})^{\wedge x}$

    x is the scale factor, usually between 0.6 and 0.9
  - Leverage known costs from other industries
  - Quantify cost savings from process scale-up

Caveats:

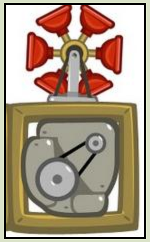
Min size – of industrial equipment available on market

Max size – at a point, multiple machines are used instead



Engine A
300 hp
$50K

Commercial model



Engine B
150 hp
$?

Your model

- **Lifetime of equipment**
  - Impacts depreciated CapEx (total cost/lifetime)
  - Maintenance schedule (downtime)

STRUCTURE THE MODEL SO ITS EASY TO FOLLOW

- Left-to-right reading
- OPEX, CAPEX sheets pull non-cost values from other sheets
- Assumptions easy to see and follow to source

Physical calculations sheet (multiple tabs by module)

Module	Parameter	Unit	Value	Assumptions & source info
Process 4	Flow rate	L/hr	(calculated output of process 3)	
	Chemical requirement	g/L	input	current usage in lab. R&D target of x g/L
	Chemical input	kg/hr	(calculated from above)	
	Floor area	m2	(calculated)	150% of tank footprint, based on xyz

(all hypothetical)

OPEX sheet

Input	Module	units/yr	$/Unit	Total $	Assumptions & source info
Electricity (kWh)	Process 3	22,000	0.08	1,760	avg. industrial rate in midwest. Source: eia.doe.gov
	Process 4	2,500	0.08		

Cost-driving physical units drawn from calcs sheets

CAPEX sheet

Module	Equipment	Scaling unit	Model Value	Basis Value	Basis Cost	Equipment Cost	Installed cost multiplier	Installed Cost
Process 4	Machine a	flow rate, m3/hr	x	y	1,000	=1000*(x/y)^0.7	3	1,234
	Machine b							

INCLUDE A SIMPLE SUMMARY PAGE

- Clearly identify assumptions for scale and capacity factor
- Total CapEx, OpEx, and $/unit
- Show financial assumptions

This model and others will be available in the group “Cost modeling resources” folder on google drive

Example from Sandia Lab’s Reference Model Project for hydrokinetic devices

Total Cost in Thousands ($)	
	1 Unit
CAPEX	Total Cost
Development	$4,553
Infrastructure	$990
Mooring/Foundation	$525
Device Structural Components	$2,939
Power Take Off	$623
Subsystem Integration & Profit Margin	$356
Installation	$5,909
Contingency	$1,590
Total	$17,485

Annual Cost in Thousands ($)	
	1 Unit
OPEX	Total Cost / yr
Insurance	$227
Environmental Monitoring & Regulatory Co	$710
Marine Operations	$27
Shoreside Operations	$142
Replacement Parts	$54
Consumables	$8
Total	$1,168

Reference Model 3 (RM3): Wave Point Absorber

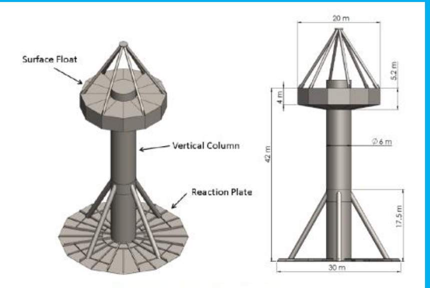
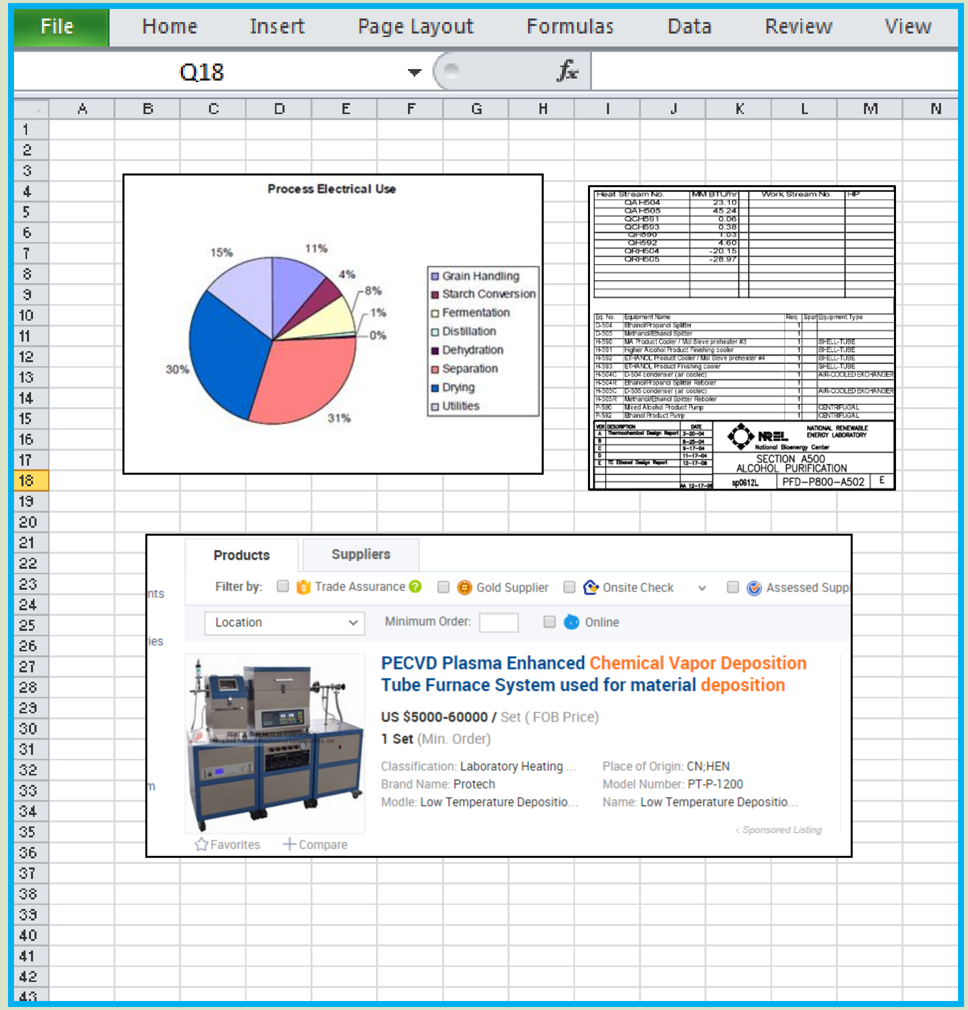


Figure 5-1. RM3 device design and dimensions.

	10 Units
	cents/kWh
Device	52.8
Infrastructure	7.8
Development	14.1
Installation	14.6
Contingency	8.9
Operation and Maintenance	47.0
Total	145.3

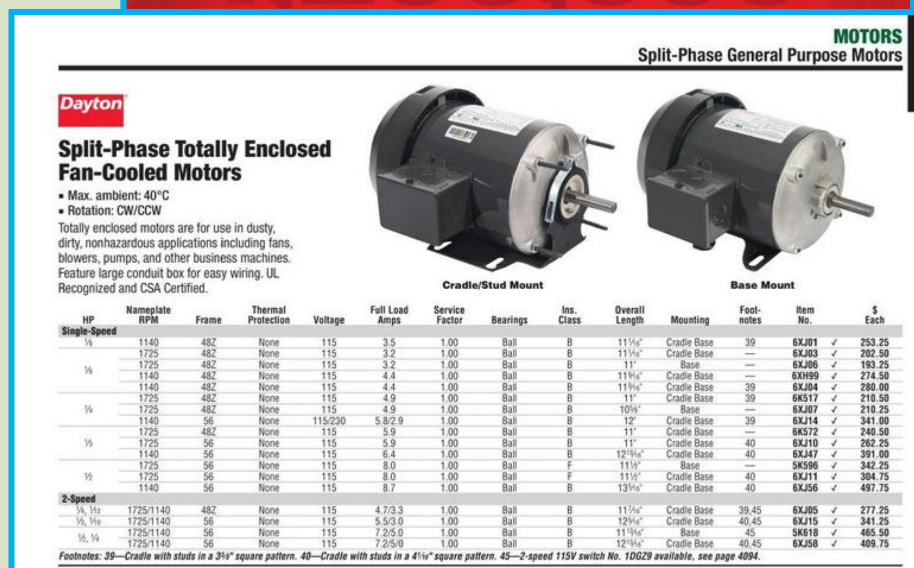
TIPS FOR THE LONG SCAVENGER HUNT: WEB

- Market reports
  - Free data only
  - Price ≠ Cost
- Tip: screenshots!
  - Google books
  - Vendor specs
  - Charts and tables
  - because you won't remember your keywords
- "How its Made" videos
  - Seeing process helps parameterize your process & equipment variables



SCAVENGER HUNT: BROKERS AND VENDORS

- Brokers
  - alibaba.com
  - specialty equipment brokers for industrial equipment
- ID the cost driving specification
  - Examples: engine power, precision of instrument, concentration, flow rate, etc.
  - Quantify relationship between spec and the cost
- Vendors and OEM (original equipment manufacturers)
  - brochures
  - salespeople
- Vendor quotes (custom equipment)
  - hard to get unless you mean business, and have detailed specs
  - very reliable if you can get them



Split-Phase Totally Enclosed Fan-Cooled Motors

- Max. ambient: 40°C
- Rotation: CW/CCW

Totally enclosed motors are for use in dusty, dirty, nonhazardous applications including fans, blowers, pumps, and other business machines. Feature large conduit box for easy wiring. UL Recognized and CSA Certified.

HP	Nameplate RPM	Frame	Thermal Protection	Voltage	Full Load Amps	Service Factor	Bearings	Ins. Class	Overall Length	Mounting	Foot-notes	Item No.		$ Each
Single-Speed														
1/8	1140	48Z	None	115	3.5	1.00	Ball	B	11 1/16"	Cradle Base	39	6XJ01	✓	253.25
1/6	1725	48Z	None	115	3.2	1.00	Ball	B	11 1/16"	Cradle Base	—	6XJ03	✓	202.50
	1725	48Z	None	115	3.2	1.00	Ball	B	11"	Base	—	6XJ06	✓	193.25
	1140	48Z	None	115	4.4	1.00	Ball	B	11 9/16"	Cradle Base	—	6XH99	✓	274.50
	1140	48Z	None	115	4.4	1.00	Ball	B	11 9/16"	Cradle Base	39	6XJ04	✓	280.00
1/4	1725	48Z	None	115	4.9	1.00	Ball	B	11"	Cradle Base	39	6K517	✓	210.50
	1725	48Z	None	115	4.9	1.00	Ball	B	10 5/8"	Base	—	6XJ07	✓	210.25
	1140	56	None	115/230	5.8/2.9	1.00	Ball	B	12"	Cradle Base	39	6XJ14	✓	341.00
1/3	1725	48Z	None	115	5.9	1.00	Ball	B	11"	Cradle Base	—	6K572	✓	240.50
	1725	56	None	115	5.9	1.00	Ball	B	11"	Cradle Base	40	6XJ10	✓	262.25
	1140	56	None	115	6.4	1.00	Ball	B	12 13/16"	Cradle Base	40	6XJ47	✓	391.00
1/2	1725	56	None	115	8.0	1.00	Ball	F	11 1/2"	Base	—	5K596	✓	342.25
	1725	56	None	115	8.0	1.00	Ball	F	11 1/2"	Cradle Base	40	6XJ11	✓	304.75
	1140	56	None	115	8.7	1.00	Ball	B	13 5/16"	Cradle Base	40	6XJ56	✓	497.75
2-Speed														
1/4, 1/12	1725/1140	48Z	None	115	4.7/3.3	1.00	Ball	B	11 7/16"	Cradle Base	39,45	6XJ05	✓	277.25
1/3, 1/10	1725/1140	56	None	115	5.5/3.0	1.00	Ball	B	12 9/16"	Cradle Base	40,45	6XJ15	✓	341.25
1/2, 1/4	1725/1140	56	None	115	7.2/5.0	1.00	Ball	B	11 13/16"	Base	45	5K618	✓	465.50
	1725/1140	56	None	115	7.2/5/0	1.00	Ball	B	12 13/16"	Cradle Base	40,45	6XJ58	✓	409.75

Footnotes: 39—Cradle with studs in a 3 1/2" square pattern. 40—Cradle with studs in a 4 1/8" square pattern. 45—2-speed 115V switch No. 1DGZ9 available, see page 4094.

SCAVENGER HUNT: EXPERTS

- Probe with questions that elicit constraints (max/min):
  - Location of bottleneck?
  - Most variable input cost?
  - Longest lead time item?
  - Highest maintenance system?
  - Age of oldest /newest equipment?
- Know process in advance
- Tour facility
- Pivot conversation if necessary

SCAVENGER HUNT: EXCEL MODELS

- Getting information from other excel models, such as
  - sources of data
  - process assumptions
  - installed cost multipliers
  - input costs
- ...but always validate on your own. Models are by definition not real, and often idealized

Parameters in BatPaC	
Number of cells per battery system	96
Number of modules per battery system	4
Number of packs per battery system	1
Battery system total energy storage, kWh	4.0
Battery power, kW	60
Nominal battery system voltage (OCV at 50% SOC),V	380
Battery capacity, Ah	10.6
Maximum current at full power, A	204
Cooling system power requirements, W	1093

Example from BatPaC (battery performance and cost) model by Argonne Lab

DO REALITY CHECKS: VALIDATE

- Interdependency requires high use of formulas = accuracy risk

  →Validate calculated values with real numbers

- Reach outside your model for real data from other industries
  - What others know, and will compare you against
  - Powerful in validating your model
  - Even if major differences exist, focus on analogies

- Real numbers - preferable to calculated numbers when you have them

- Results too good to be true? then they probably aren't

WHEN TO USE SCENARIOS

- Consider scenarios when
  - Qualitative system differences
  - Pilot/commercial scale

- Pilot/Commercial scenarios
  - Pilot - uses near term technical targets → market entry cost
  - Commercial – long-term, external communication, the possible

- Example differences
  - Pilot uses outsourced inputs (materials, labor, leased equipment) that become in-house at commercial scale
  - Step-change cost reductions at scale
  - Pilot is retrofit, commercial is new construction


POTATO CHIP FACTORY