HOW TO BUILD A GOOD COST MODEL

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HOW TO BUILD A GOOD COST MODEL

AGENDA

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

Full Company Financial Model
- Cash flow, dynamics of ramping production and varying sales, investments timing
- Similar information for other projects competing for resources

Production Cost Model
- Determine resources required for at-scale production
- Tabulate material/component flow, labor & energy use, equipment, etc

Basic Materials & Process
- Bill of Materials (BOM) - list of “ingredients”
- Simple block diagram of production steps

Most performers begin with a basic form of “Production Cost Model”
PRODUCTION COST MODEL BOTTOM-LINE NUMBERS

Hypothetical factory, simplified cost structure

CAPEX, ($)
Also known as: capital expenditure, capital cost, investment cost, upfront cost

OPEX, ($/yr)
Also known as: operating expenditure, operating cost

Land

Design & Engineering

Equipment

Installation

CapEx/yr

Depreciation, ($/yr)

CapEx/unit

OpEx/unit

Unit cost, ($/unit)
+ business costs: interest on loan, taxes, etc. (part of financial model)

Labor

Fuel

Materials

/equipment lifetime

/units/yr

/equipment lifetime

/units/yr

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

Also known as: operating expenditure, operating cost
Comparing options for producing the 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

This is a picture from Bad Piggies where you design a go-cart to navigate an obstacle course. Design and redesign the cart to achieve target performance.
DEFEAT SKEPTICISM: SHOW YOUR ASSUMPTIONS

REAL DATA → Show assumptions! → Modeled physical system → COST
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

- **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
    \[\text{Cost } B = \text{Cost } A \times (\frac{\text{Output } B}{\text{Output } A})^x\]
    
    - \(x\) 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

- **Lifetime of equipment**
  - Impacts depreciated CapEx (total cost/lifetime)
  - Maintenance schedule (downtime)
### Physical calculations sheet (multiple tabs by module)

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

(all hypothetical)

### OPEX sheet

<table>
<thead>
<tr>
<th>Input</th>
<th>Module</th>
<th>units/yr</th>
<th>$/Unit</th>
<th>Total $</th>
<th>Assumptions &amp; source info</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity (kWh)</td>
<td>Process 3</td>
<td>22,000</td>
<td>0.08</td>
<td>1,760</td>
<td>avg. industrial rate in midwest. Source: eia.doe.gov</td>
</tr>
<tr>
<td>Process 4</td>
<td>2,500</td>
<td>0.08</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### CAPEX sheet

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

Cost-driving physical units drawn from calcs sheets
INCLUDE A SIMPLE SUMMARY PAGE

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

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

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

<table>
<thead>
<tr>
<th>Reference Model 3 (RM3): Wave Point Absorber</th>
</tr>
</thead>
<tbody>
<tr>
<td>![Wave Point Absorber Diagram]</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Annual Cost in Thousands ($)</th>
<th>1 Unit</th>
<th>Total Cost / yr</th>
<th>10 Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>OPEX</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Insurance</td>
<td>$227</td>
<td>$2,270</td>
<td>52.8</td>
</tr>
<tr>
<td>Environmental Monitoring &amp; Regulatory Co</td>
<td>$710</td>
<td></td>
<td>7.8</td>
</tr>
<tr>
<td>Marine Operations</td>
<td>$27</td>
<td>$270</td>
<td></td>
</tr>
<tr>
<td>Shoreside Operations</td>
<td>$142</td>
<td>$1,420</td>
<td></td>
</tr>
<tr>
<td>Replacement Parts</td>
<td>$54</td>
<td>$540</td>
<td></td>
</tr>
<tr>
<td>Consumables</td>
<td>$8</td>
<td>$80</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>$1,168</td>
<td></td>
<td>145.3</td>
</tr>
</tbody>
</table>
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
**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**
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.

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**Parameters in BatPaC**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of cells per battery system</td>
<td>96</td>
</tr>
<tr>
<td>Number of modules per battery system</td>
<td>4</td>
</tr>
<tr>
<td>Number of packs per battery system</td>
<td>1</td>
</tr>
<tr>
<td>Battery system total energy storage, kWh</td>
<td>4.0</td>
</tr>
<tr>
<td>Battery power, kW</td>
<td>60</td>
</tr>
<tr>
<td>Nominal battery system voltage (OCV at 50% SOC), V</td>
<td>380</td>
</tr>
<tr>
<td>Battery capacity, Ah</td>
<td>10.6</td>
</tr>
<tr>
<td>Maximum current at full power, A</td>
<td>204</td>
</tr>
<tr>
<td>Cooling system power requirements, W</td>
<td>1093</td>
</tr>
</tbody>
</table>

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