Techno-Economic Analysis at ARPA-E

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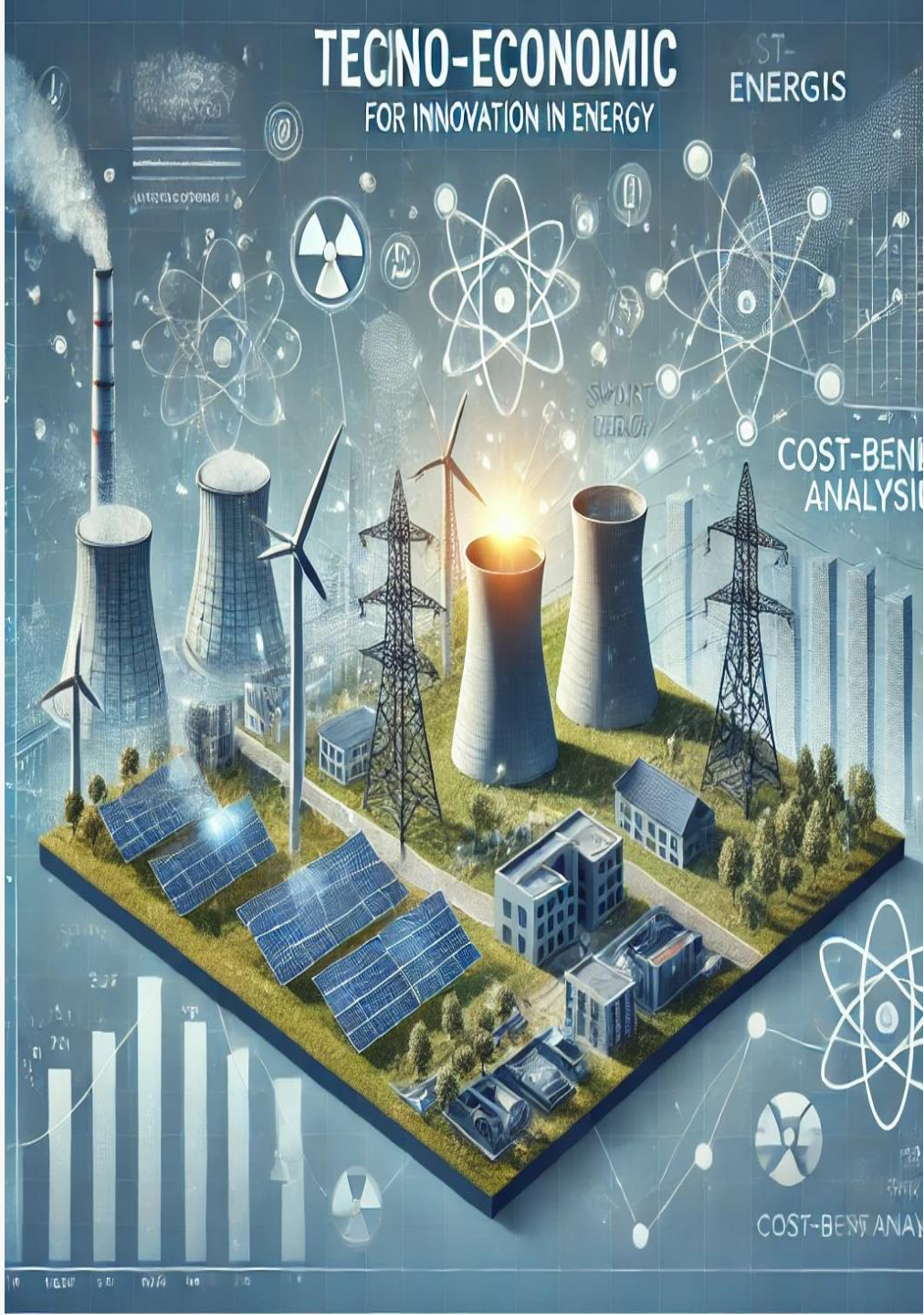


What is Techno-Economic Analysis (TEA)

Method for evaluating the economic performance of a technology. It assesses life-cycle costs, benefits, risks and timeframe to evaluate a technology.

Key Components:

- Technical Assessment – Technical feasibility, process design, scalability and performance against baseline.
- Economic Analysis – Costs (capital, operating and end of life), and revenue/benefit as appropriate.
- Financial Modeling – Translate technical and economical findings into actionable financial strategies.

Types of TEA

- The complexity and importance of the TEA of a new technology increases along the stage of development and knowledge of market.
  - **Level 1: Screening TEA** will provide a preliminary estimate of the **cost of production** of a system at scale which will be used to calculate LCOx (Levelized Cost Of X; e.g. Energy, Storage, etc.).
  - **Level 2: Expanded TEA** will provide a more accurate estimates of the **cost of production** of a system and builds up on more accurate input values than those used in screening TEA. It provides information to support decision making on intermediate investments
  - **Level 3: Detailed TEA / Financial Modeling** will provide detailed estimate of the **cost of production and projected revenue** that allows detailed information for analysis to support decision-making on substantial investments.

- TEA is the **methodology** and LCOx is one **metric.**

Appropriate TEA varies with commercial and technological maturity

Modeling Approach Alternatives

Market Maturity

	Level 1: Screening *(Early-stage R&D)*	**Level 2: Expanded** *(Pilot Scale)*	**Level 3: Detailed** *(Commercial Deployment)*
High *(Established Market, Proven Business Model)*	Basic R&D Economic Viability (fundamental economic constraints, theoretical cost floors, technology cost benchmarks)	Commercial Scaling & Optimization (process-based cost modeling, industrial cost reductions, supply chain modeling, economies of scale analysis)	Mature Market Competitiveness Modeling (e.g., comparative cost analysis, competitive pricing models, policy impact modeling)
Medium *(Developing Market, Limited Adoption)*	Techno-Economic Feasibility (early-stage CAPEX/OPEX modeling, learning curves, TRL-based cost projections)	System Integration & Scaling Models (cash flow projections, Monte Carlo simulations, infrastructure investment modeling)	Investment & Business Case Modeling (e.g., NPV, IRR, risk-adjusted cost modeling)
Low *(Emerging Market, Unproven Business Model)*	Exploratory Modeling (fundamental feasibility studies - e.g., process/cost estimation, cost-benefit analysis, scenario analysis)	Market Entry Feasibility Analysis (e.g., cost curves, sensitivity analysis, regulatory impact assessment)	Break-even & Payback Analysis (e.g., financial viability studies, LCOE/LCOx, PPA pricing models)

Technology Maturity

Techno-economic analyses of a technology over its evolution

Level	Technology Stage	Assessment Process	Process	Questions to answer
1	Early (Lab Scale)	**Screening TEA** Cost analysis Comparison with alternative technology	1. Identify baseline for comparison 2. Conceptual product/process design 3. Estimate CAPEX and OPEX for each process in scope 4. Simplified (High-Level) Cost Analysis	1. Does the technology provide more value/product than existing alternative? 2. What are the main costs used as inputs for analysis? 3. What is minimum performance levels to have technology economically feasible? 4. What processes/components are most influential and should be prioritized in further R&D?
2	Intermediate (Lab to Pilot)	**Expanded TEA** Detailed Cost Analysis (DCA) Cost sensitivity analysis Discounted Cash Flow (DCF) Life Cycle Analysis (LCA)	1. Develop process block diagram 2. Develop product design and manufacturing process block diagram 3. Refine Cost Analysis with new-insights from technology development 4. Estimate projected revenue 5. Estimate break-even point, return-on-investment, other financial metrics 6. Incorporate new-insights from technology development and process data collection	1. Should continue development given the knowledge acquired from lab/pilot scale experiments? 2. What processes/components are most influential and should be prioritized in further R&D? 3. What minimum performance levels at scale will be necessary to have an economically feasible design/process? 4. What is the estimated long-term profitability of project? 5. Is the technology investable? Sustainable?
3	Late (Pilot to Pre-Commercial)	**Detailed TEA/Financial Modeling** Process Based Cost Modeling (PBCM) Discounted Cash Flow (DCF) Scenario sensitivity analysis Life Cycle Analysis (LCA)	1. Update data from previous stages 2. Detail process model / product design 3. Refine costs & revenue estimation / consider scaling factors 4. Integrates financial analysis with broader strategic objectives, assessing the project's impact on company's performance	1. What processes/components are most influential and should be prioritized in further R&D? 2. Were the engineering and manufacturing risks removed? 3. What are the effects of efficiency, yield and costs? 4. Are the market risks removed (revenue projections)? 5. Should investment to build commercial system be pursued?

Definitions

Basic Financial Analysis (Level 1; Screening TEA)

- Costs Analysis: Focus on understanding the direct and indirect costs associated with developing and launching the product/technology
- Comparison with competing technology

Intermediate Financial Analysis (Level 2; Expanded TEA)

- Detailed Cost Analysis: includes a more thorough examination of costs, considering factors like fixed vs. variable costs, labor costs, materials costs
- Revenue Projections: Establishes a basic understanding of potential sales and revenue streams
- Discount Cash Flow Analysis: Calculates the present value of future cash flows to assess project's long term
- Break-Even Analysis: Determines the point at which the product costs are covered by revenue
- Simple Return on Investment (ROI) Calculation: A basic measure of the potential profitability of the project

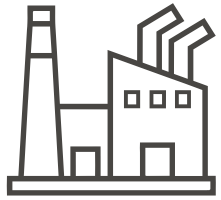
Advanced Financial Analysis (Level 3; Detailed TEA / Financial Modeling)

- Scenario Planning: Develops multiple scenarios (e.g. optimistic, pessimistic, most likely) to assess project's potential outcomes under different conditions
- Process Based Cost Modeling: Model of cost of product or process by analyzing individual processes of involved in its production. PCBM breaks down operations into specific tasks or process steps and assign costs to each.
- Strategic Financial Analysis: Integrates financial analysis with broader strategic objectives, assessing the project's impact on the company's overall performance
- Sensitivity analysis of Multiple Variables: Examines the impact of changes in multiple key assumptions simultaneously

TEA is an evolving instrument through the life of a project

Technical knowledge from R&D

- Performance, yields and efficiencies
- Raw material quantities & ratios
- Reaction rates, conversions rates



Engineering assumptions

- Efficiencies or power for equipment
- Process flow diagram
- Product definition
- Product / process performance
- Capital / Equipment costs

Prices & cost correlations

- Price of raw materials, products, disposal, and utilities
- Correlations for upscaling equipment and capacity
- Factors for estimating other costs

Project Proposal → Project Execution → Project Follow-on

Screening TEA

- Preliminary assessment of impact of technology and economic viability

Expanded TEA

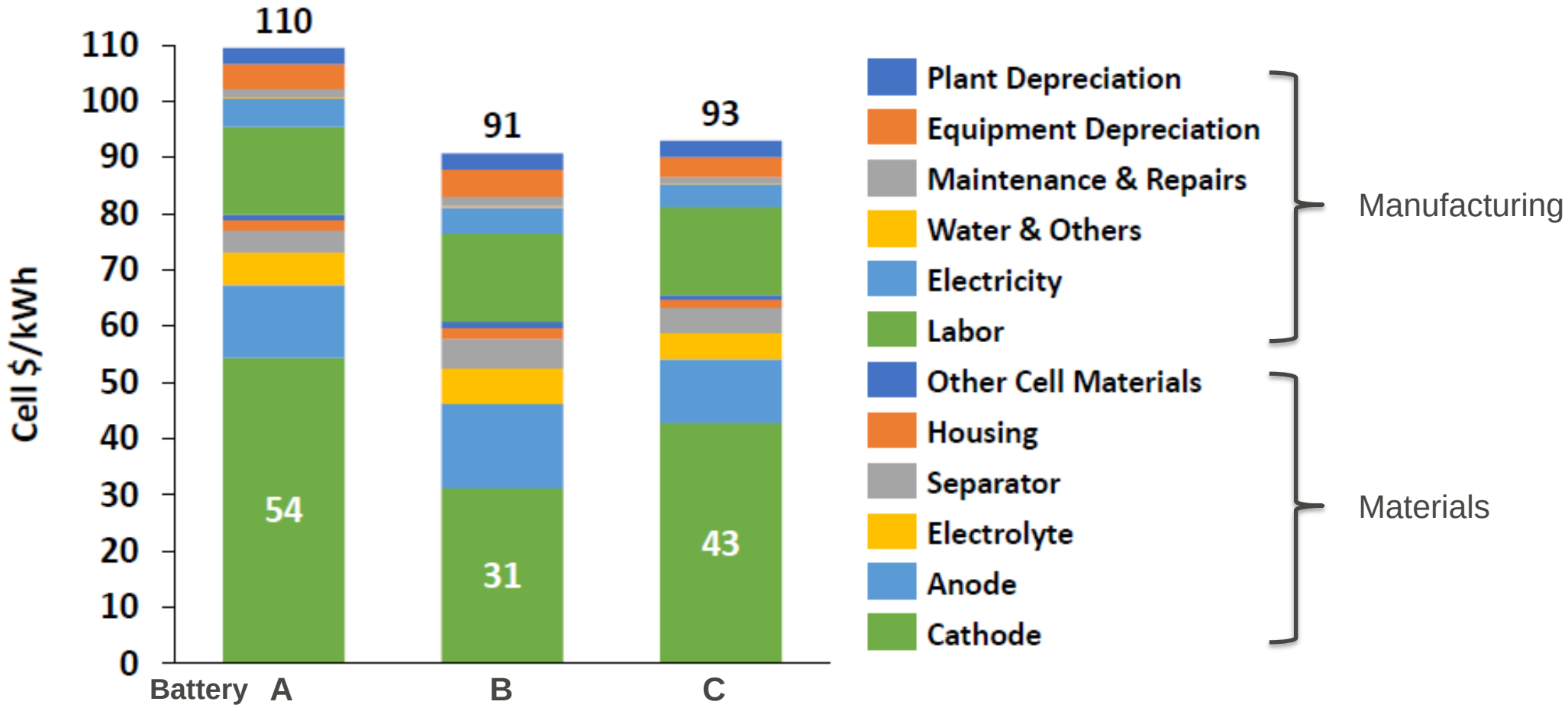
- Continuously refined during the project execution
- Provides feedback for technology development

Detailed TEA & Financial Model

- Prepared for activities such as follow-on investment

Example TEA for a product

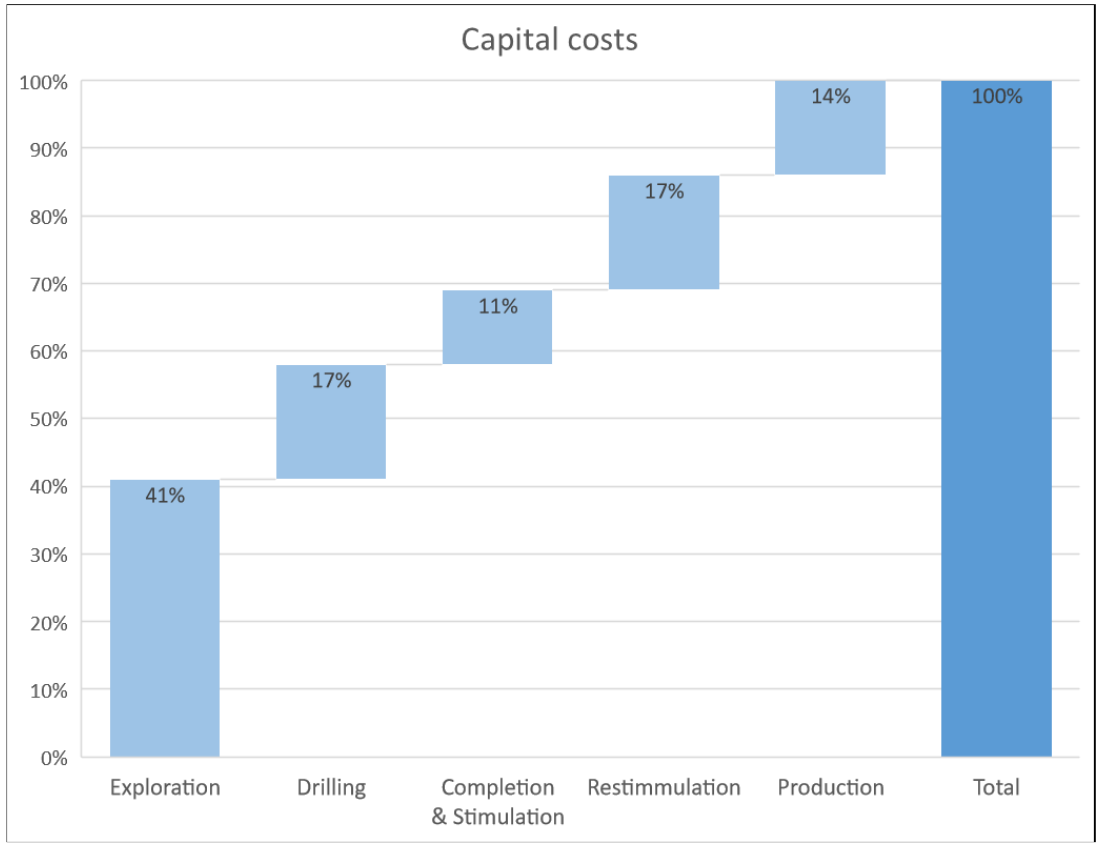
BATTERY CELL – PRODUCTION COSTS ONLY

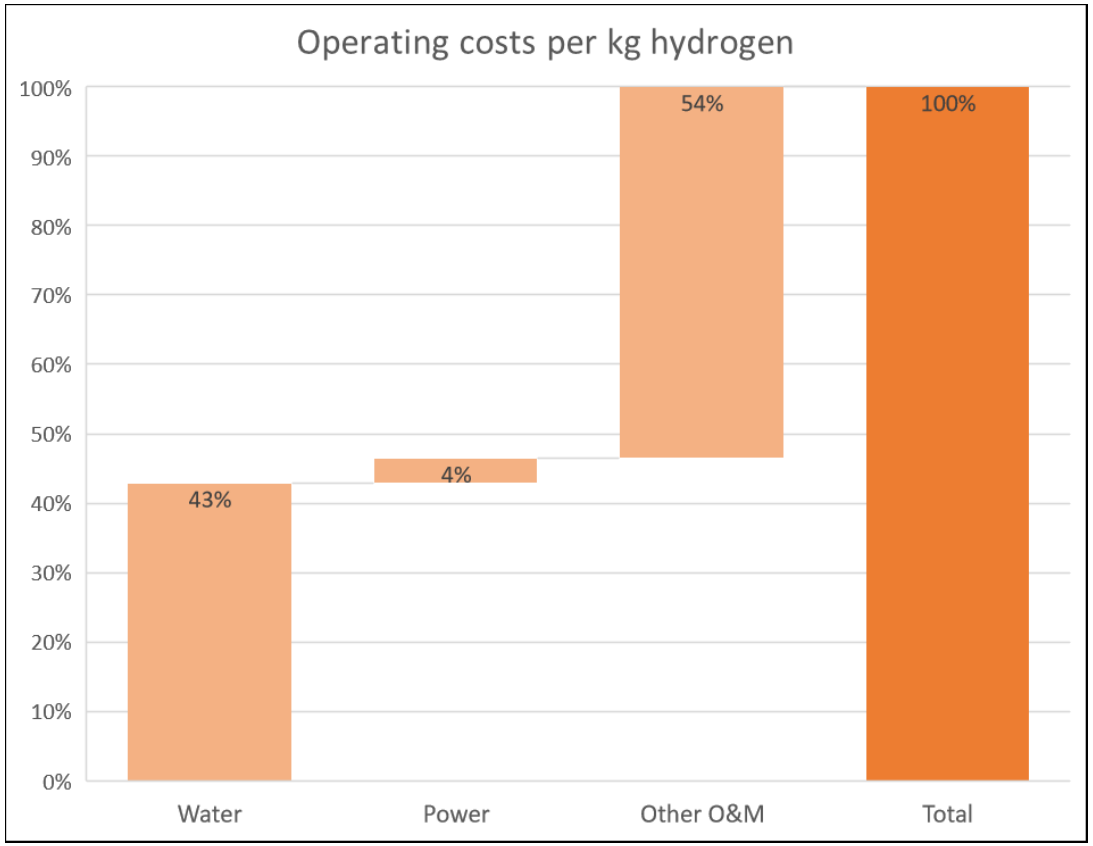


	A	B	C
Manufacturing share of cost	27%	34%	30%

Example TEA for natural resource development

EXPLORATION AND PRODUCTION OF GEOLOGIC HYDROGEN





Approaches for collecting TEA data

Approach	Pros	Potential difficulties	Ways to simplify
Get direct quotes from manufacturers /contractors	• Most accurate	• Potentially time-intensive • May require authorization for outside contact • Rare to get a response if you don't appear to be a serious (IP concerns) or near-term (uncertainty around future costs or production/service) customer	• Only seek quotes for the components/services you expect to be most expensive
Use estimating charts	• Comprehensive indices exist for both plant and equipment costing (e.g., M&S Cost Index, and Chemical Engineering Index)	• Inflation and scaling factors are not always helpful considering that tech changes over time, inflation can occur at different rates for different equipment • Access to up-to-date indices like M&S and CE is subscription-based	• Use open-access inflation and scaling factors (may not be up-to-date, but can enable the order-of-magnitude estimates that are often sufficient for early TEA work)
Review academic literature for cost-relevant data	• Good (and often necessary) for data on emerging/not-yet-commercial technologies	• Journal access needed • Data will likely need to be scaled • Sometimes the best that can be found on new tech is materials/energy input data	• Use academic literature to identify key differences between a new technology and conventional tech that could drive cost differences
Process modeling (e.g., Aspen)	• Simultaneously estimate cost and performance data, scaling often built-in	• Need a license to access most software	

Some TEA approximation tips

- Attempt to estimate **upper** and **lower bounds** for input values that are uncertain
  - Use these bounds to understand the magnitude of uncertainty of a particular data point and how much this uncertainty impacts the total production cost.
  - Uncertain data points can always be revisited if they are major drivers of TEA results, and if they aren't major drivers, you can avoid spending too much time trying to get an accurate estimate

Useful links for early-stage TEA

TEA/LCA PRIMER FOR EARLY-STAGE TECHNOLOGIES

- Life Cycle Assessment and Techno-Economic Analysis Training | Department of Energy (from DOE)
- Techno-Economic Analysis | Energy Analysis | NREL
- Article on how Technoeconomic Analyses Pave the Way to a Low-Carbon Future (lbl.gov)
- Introductory Tutorial by Activate
- A Practical Guide to Techno-Economic Analysis | AIChE
- A Simple Founder's Guide to TEAs. | by Planet A Ventures | Medium
  - Planet A-Techno Economic Analysis Template - Google Sheets
- The Unignorable Economics of Turning Science Into Technology — Homeworld Collective
- The Techno-Economic Assessment and Life Cycle Assessment Toolkit | Global CO2 Initiative
- YouTube Video - Bioenergy 101: Techno-Economic Analysis (TEA)
- Approach and Methodology for Techno-economic Analysis of PV Modules
- General TEA Templates and Videos for CCUS

Note: This list is not meant to be comprehensive nor an endorsement of any specific model, assumptions, or approach

THE END

QUESTIONS TO
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