A Practical Guide to TEA

For Venture Center

May 15, 2025

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Unsplash & DALL·E 2

Where do you get your **conviction** to go on this long journey?

About me: TEAs for early-stage climate

How I got here

Industrial engineering → Mining, chemicals → AI models for insurance → Hardtech/climate entrepreneurship → Commercial support for early-stage climate → Scaling idiosyncratic commercial support

COLUMBIA ENGINEERING

McKinsey & Company

GUIDEWIRE

Harvard Business School

picogreens

Breakthrough Energy Fellows

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PROJECT SPINOUT

Today's agenda

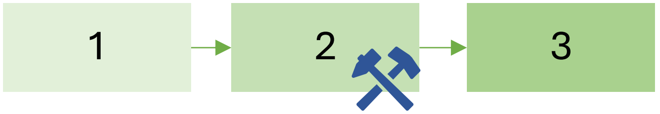
Why do you need a TEA?	15min	• Let's build the mental model first! • TEA = Analytical foundation for your company
What does good look like?	15min	• TEA for early stage comes in different sizes • Building trust in your model
How do you build one?	20min	• The steps to get started • Walking through an example
Now what?	5min	• Some resources & frameworks • Reach out if you're interested in help with TEA!

Big picture

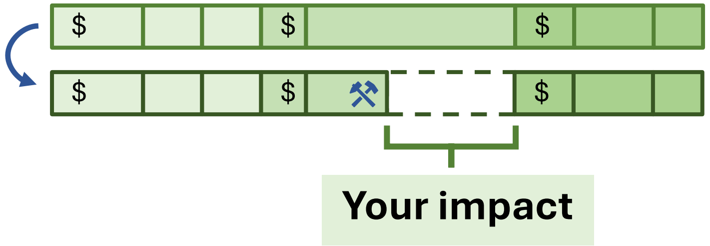
TEA in a nutshell

Start with your **core technology's** specs & value props

Integrate it into the **real-world process flow**



Overlay the economics (costs, revenues)



TEA

Drive decisions

R&D:
- Prioritize R&D targets
- Set milestones

Go-to-market
- Target market feasibility
- Revenue model

Scale-up
- Pilot sizing
- Fundraising cash flow needs

Tool for communication

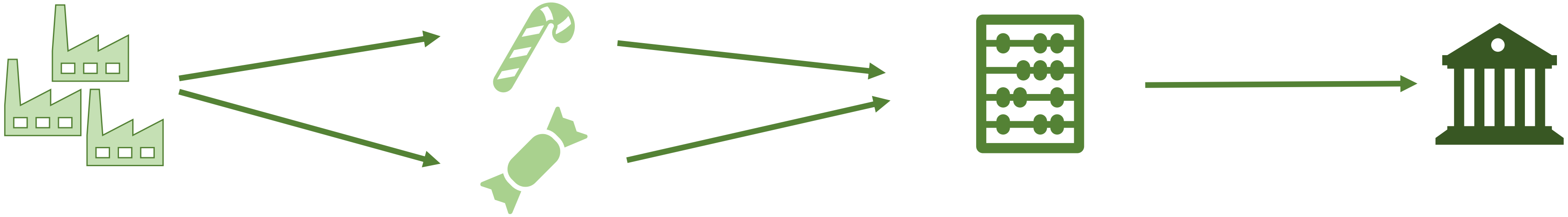
Your team
- Convince great people to join
- How workstreams relate to impact

Investors
- Own the narrative for diligence
- Isolate 'bets' they want to sign up for

Partners
- Enable feedback on implementation
- Provide better data and assumptions

Big picture

TEA's role in commercialization & strategy



Cost models @ project level

- Cost per unit (variable, fixed costs)
- Volumes
- Sensitivities

Revenue model (A)

- Addressable market (TAM, SAM, SOM)
- Pricing
- GTM strategy

Revenue model (B)

Company level financial models

- Company level GTM
- Pro forma profitability, projections
- Income statements, cash flow

Valuation model

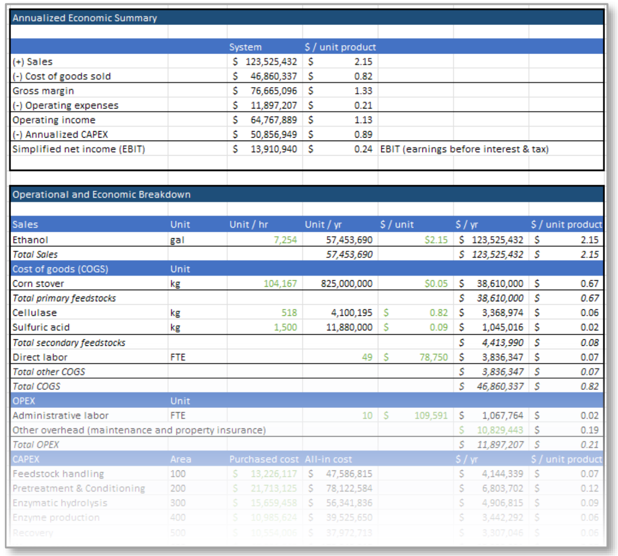
- Capital needs
- Fundraising planning
- Equity terms
- Return on investment for investors

TEA output: some consolidated financial metric *(gross margin, cash flow, rate of return)*

The mental model

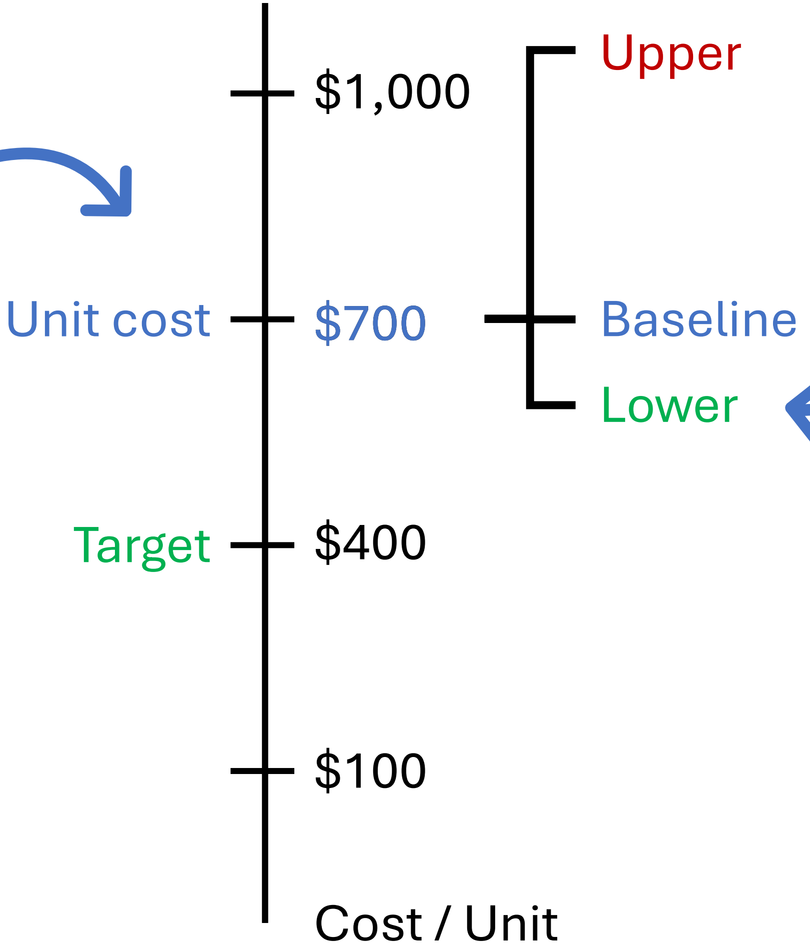
Let's skip ahead – Let's see a TEA in action

Unit Cost Summary

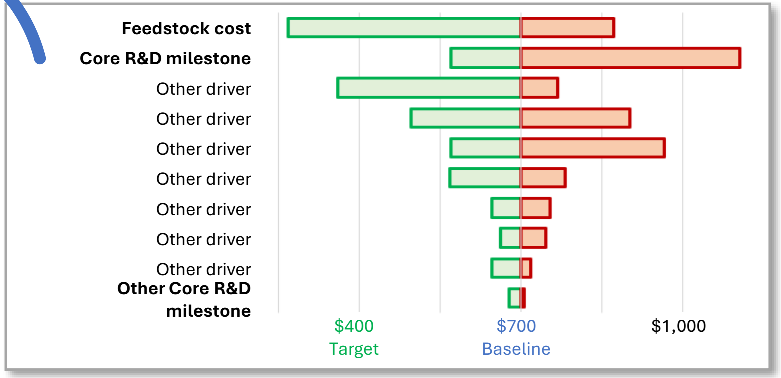


Annualized Economic Summary			
	System	$ / unit product	
(+) Sales	$ 123,525,432	$ 2.15	
(-) Cost of goods sold	$ 46,860,337	$ 0.82	
Gross margin	$ 76,665,096	$ 1.33	
(-) Operating expenses	$ 11,897,207	$ 0.21	
Operating income	$ 64,767,889	$ 1.13	
(-) Annualized CAPEX	$ 50,856,949	$ 0.89	
Simplified net income (EBIT)	$ 13,910,940	$ 0.24	EBIT (earnings before interest & tax)

Operational and Economic Breakdown						
Sales	Unit	Unit / hr	Unit / yr	$ / unit	$ / yr	$ / unit product
Ethanol	gal	7,254	57,453,690	$2.15	$ 123,525,432	$ 2.15
Total Sales			*57,453,690*		*$ 123,525,432*	*$ 2.15*
Cost of goods (COGS)	Unit					
Corn stover	kg	104,167	825,000,000	$0.05	$ 38,610,000	$ 0.67
Total primary feedstocks					*$ 38,610,000*	*$ 0.67*
Cellulase	kg	518	4,100,195	$ 0.82	$ 3,368,974	$ 0.06
Sulfuric acid	kg	1,500	11,880,000	$ 0.09	$ 1,045,016	$ 0.02
Total secondary feedstocks					*$ 4,413,990*	*$ 0.08*
Direct labor	FTE		49	$ 78,750	$ 3,836,347	$ 0.07
Total other COGS					*$ 3,836,347*	*$ 0.07*
Total COGS					*$ 46,860,337*	*$ 0.82*
OPEX	Unit					
Administrative labor	FTE		10	$ 109,591	$ 1,067,764	$ 0.02
Other overhead (maintenance and property insurance)					$ 10,829,443	$ 0.19
Total OPEX					*$ 11,897,207*	*$ 0.21*
CAPEX	Area	Purchased cost	All-in cost		$ / yr	$ / unit product
Feedstock handling	100	$ 13,226,117	$ 47,586,815		$ 4,144,339	$ 0.07
Pretreatment & Conditioning	200	$ 21,713,125	$ 78,122,584		$ 6,803,702	$ 0.12
Enzymatic hydrolysis	300	$ 15,659,458	$ 56,341,836		$ 4,906,815	$ 0.09
Enzyme production	400	$ 10,985,624	$ 39,525,650		$ 3,442,292	$ 0.06
Recovery	500	$ 10,554,006	$ 37,972,713		$ 3,307,046	$ 0.06



Sensitivity Analysis



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Baseline question: Are you in the ballpark?

Unit Cost Summary

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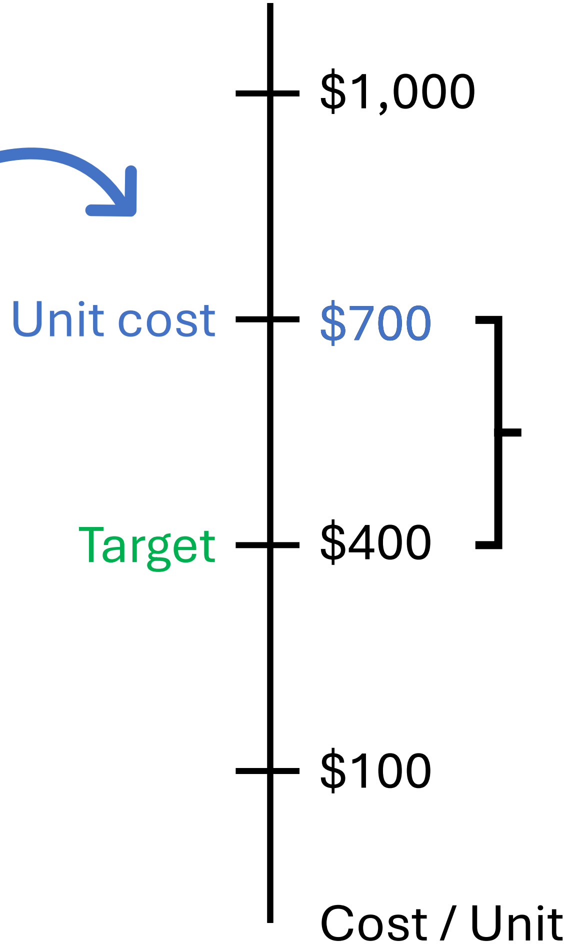

Maybe. How could you bridge the gap?

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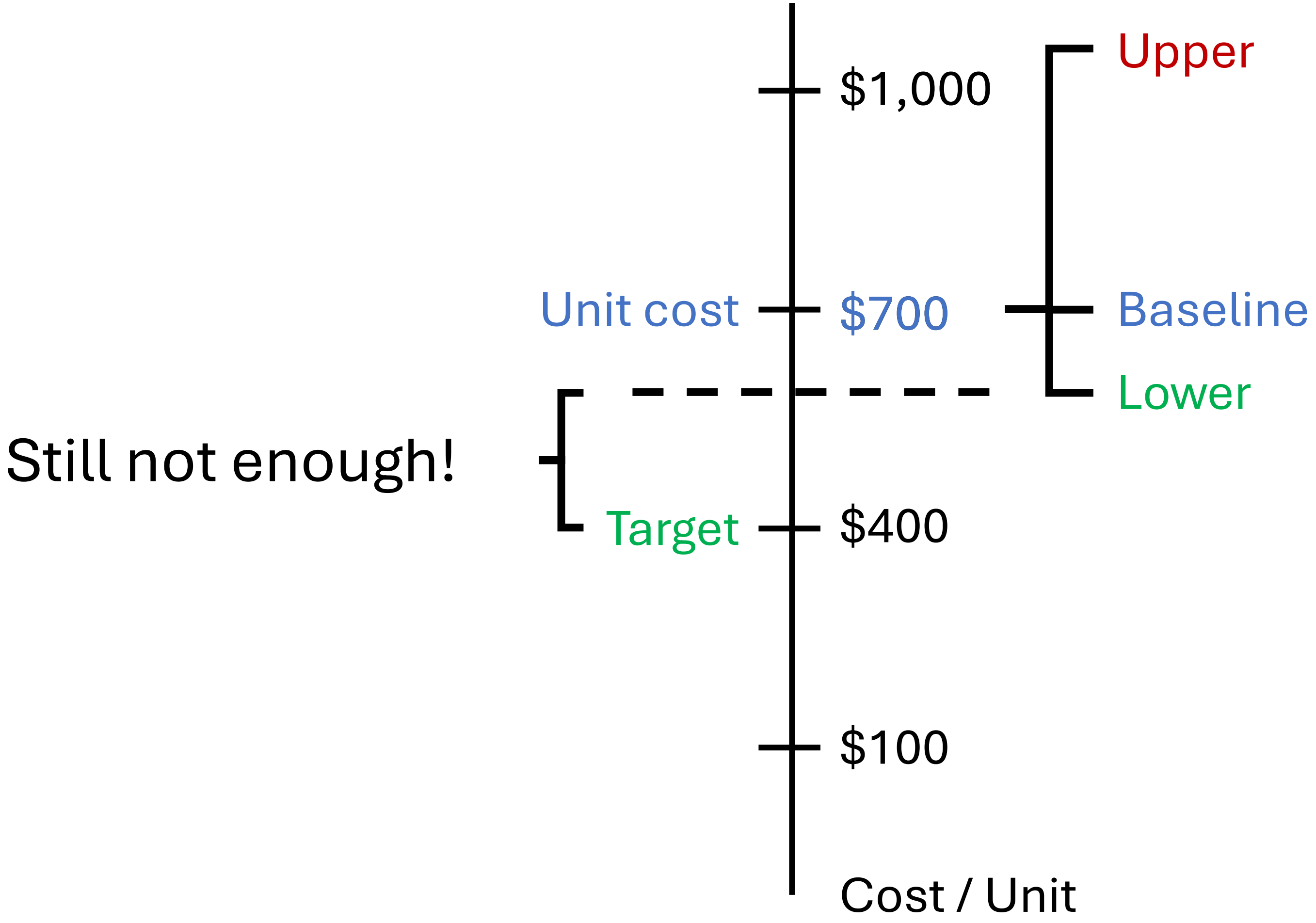
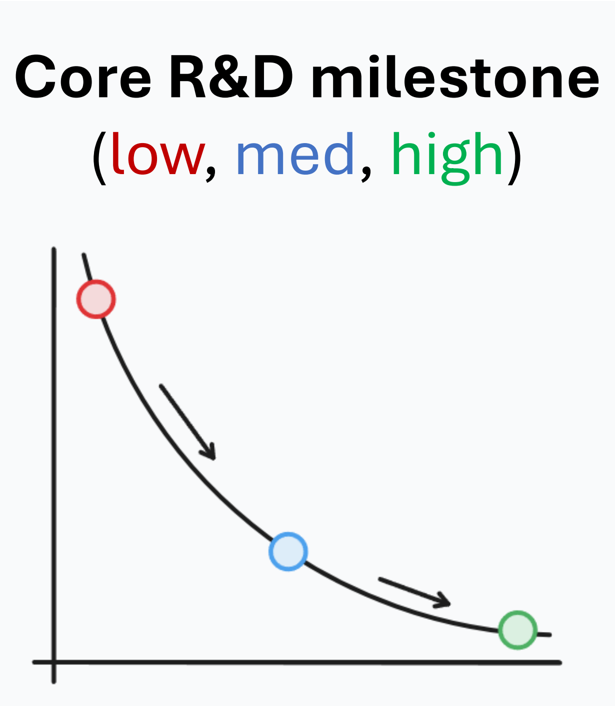
The mental model

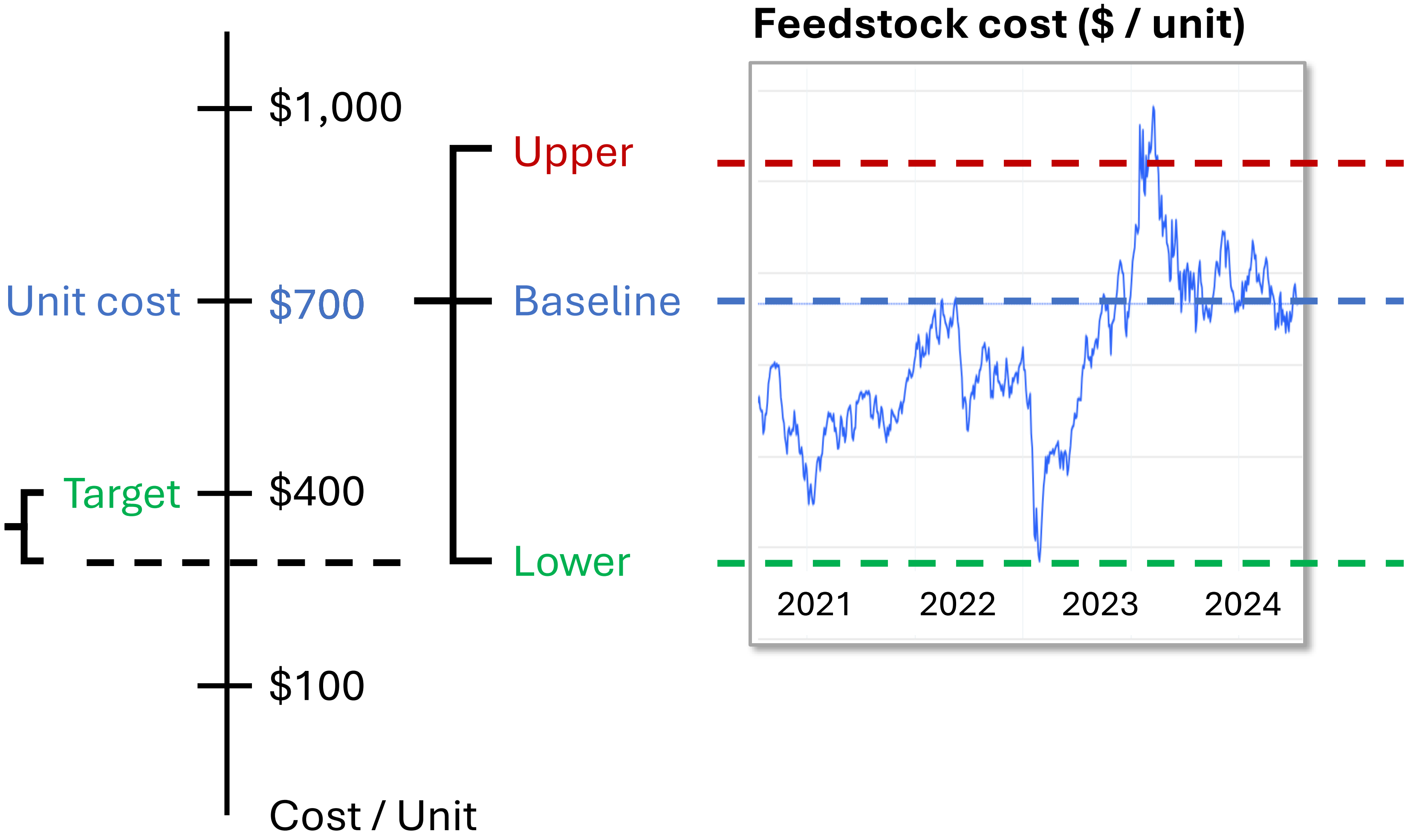
Try adjusting core assumptions





Or try adjusting other assumptions

Looking good!
But it's also out of your hands



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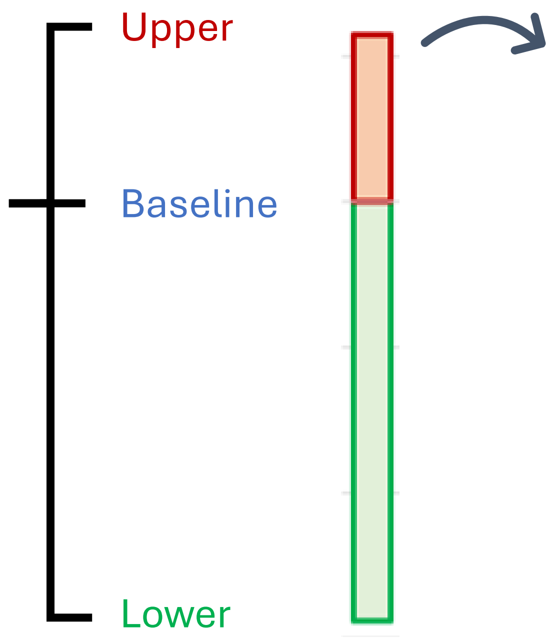
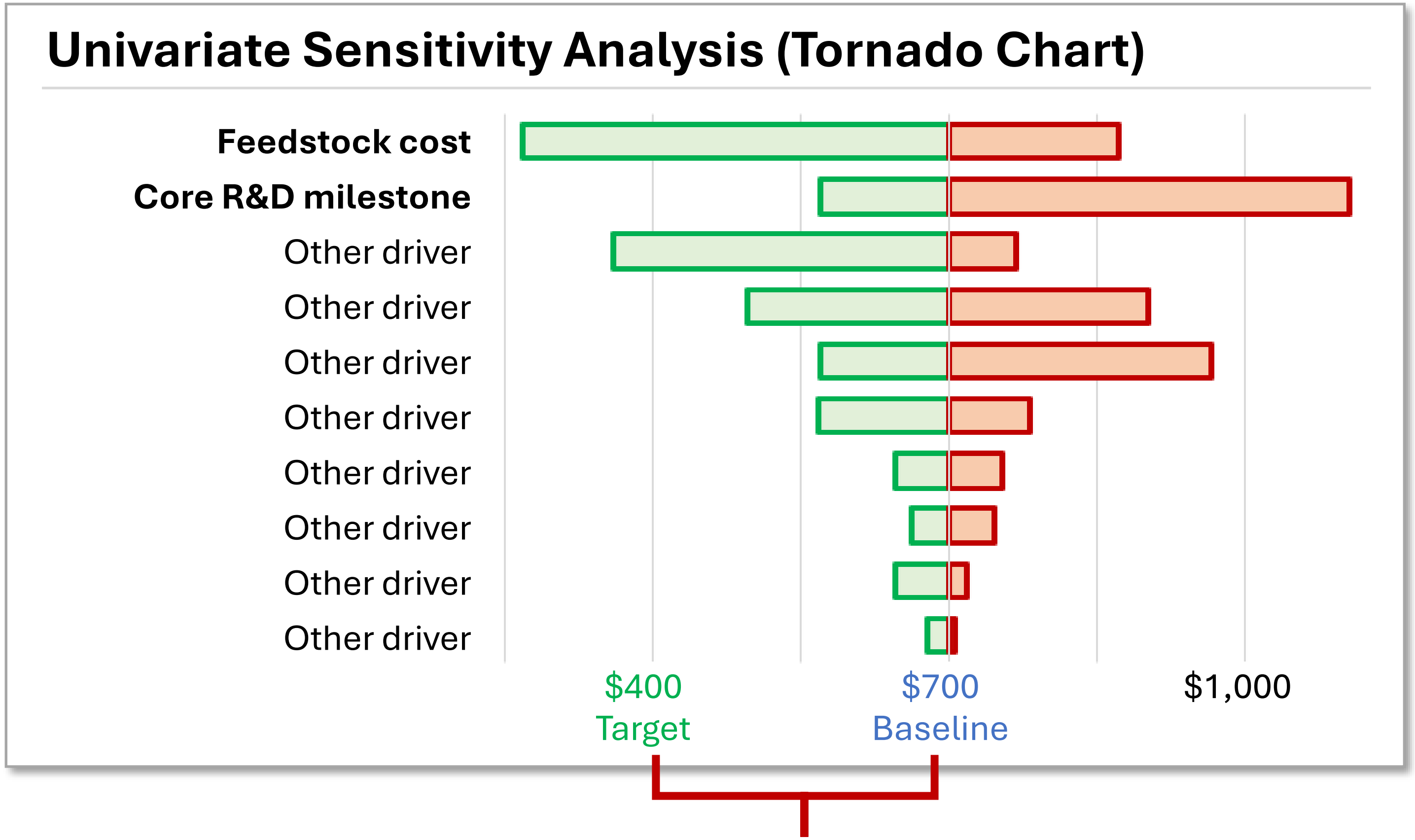
The mental model

Tornado Chart: stack ranked adjustments



Unit cost impact of adjusting
“Feedstock Cost”



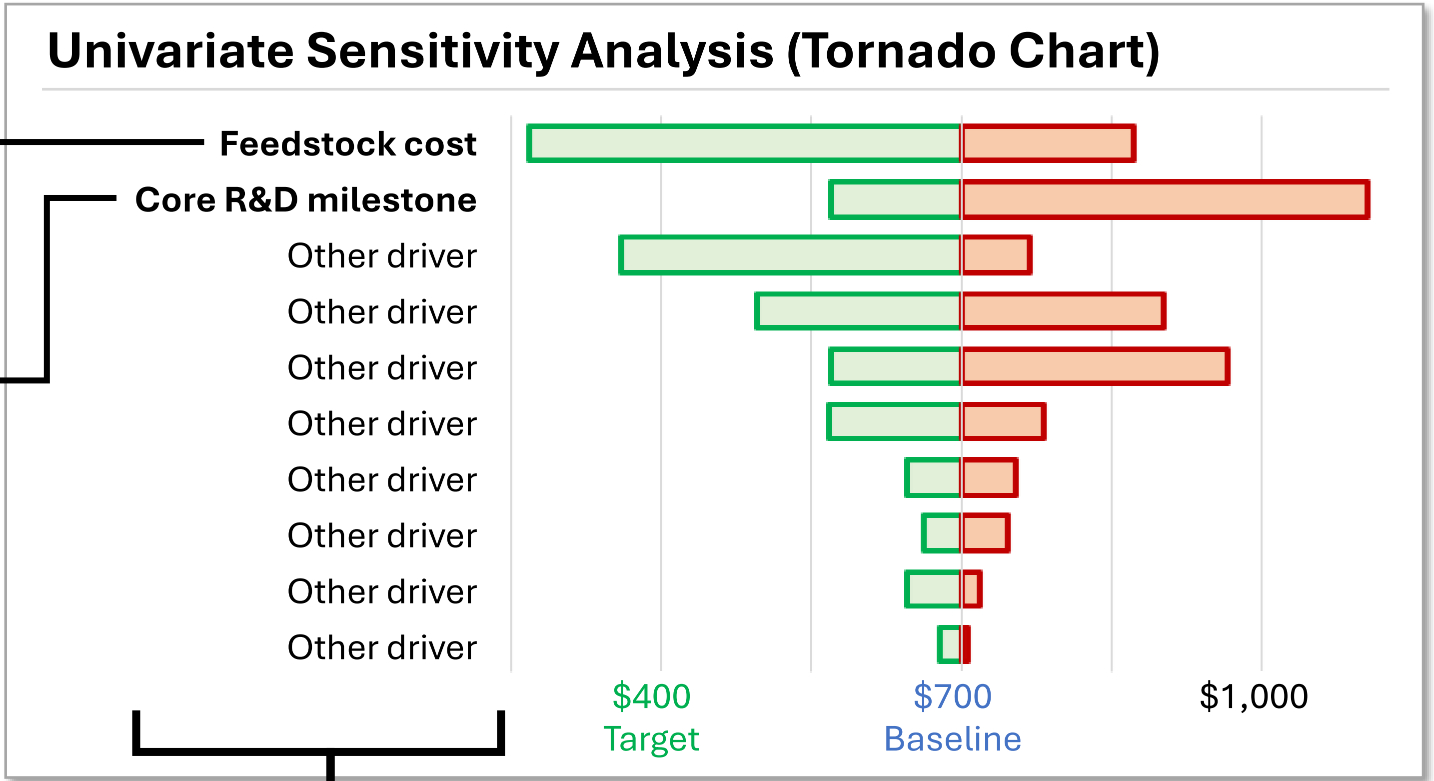
What would you **have to believe** to bridge this gap?

The mental model

Start by making sense of these “bets”

Outside of your control

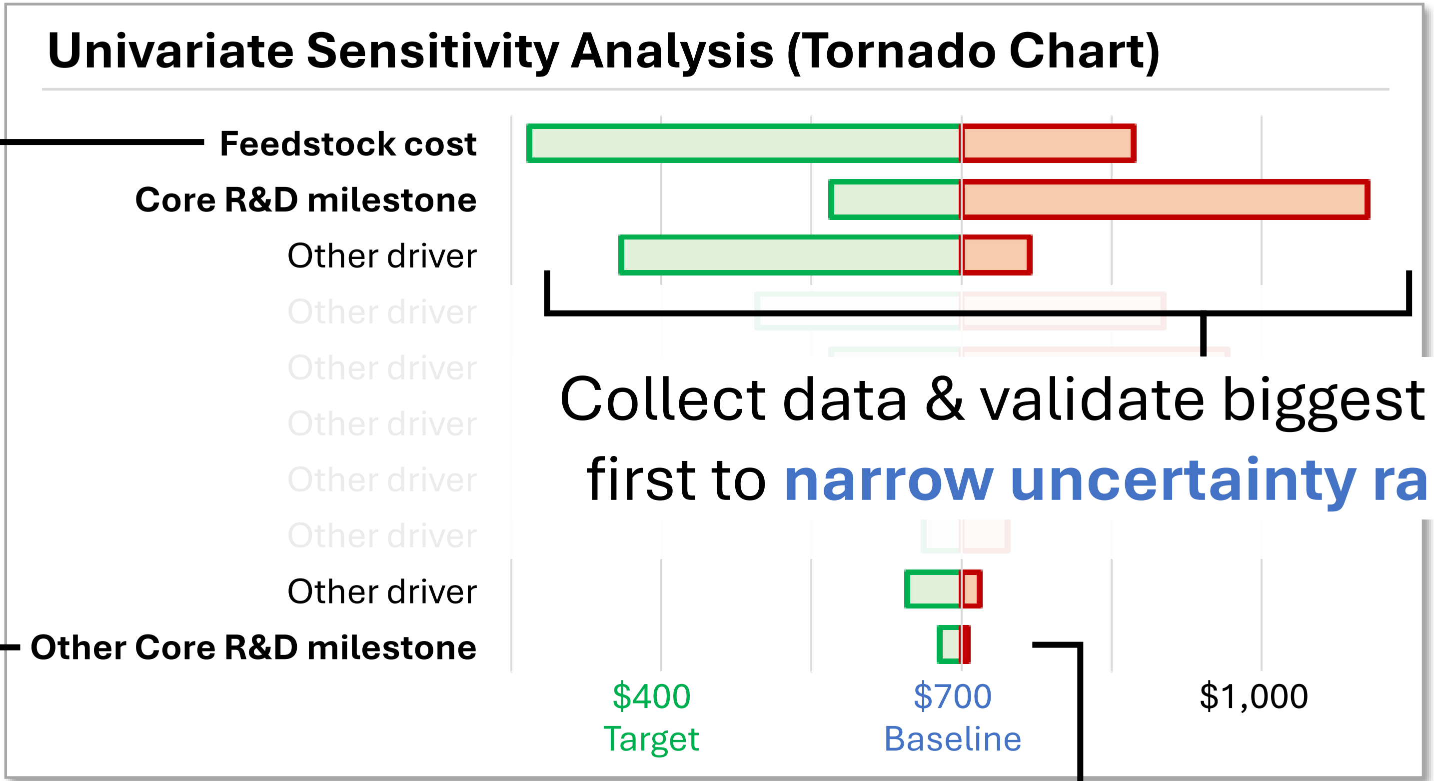
More **within** your control



Your belief: **some combination & outcomes** of these bets can bridge the gap

The mental model

Turn these insights into actions



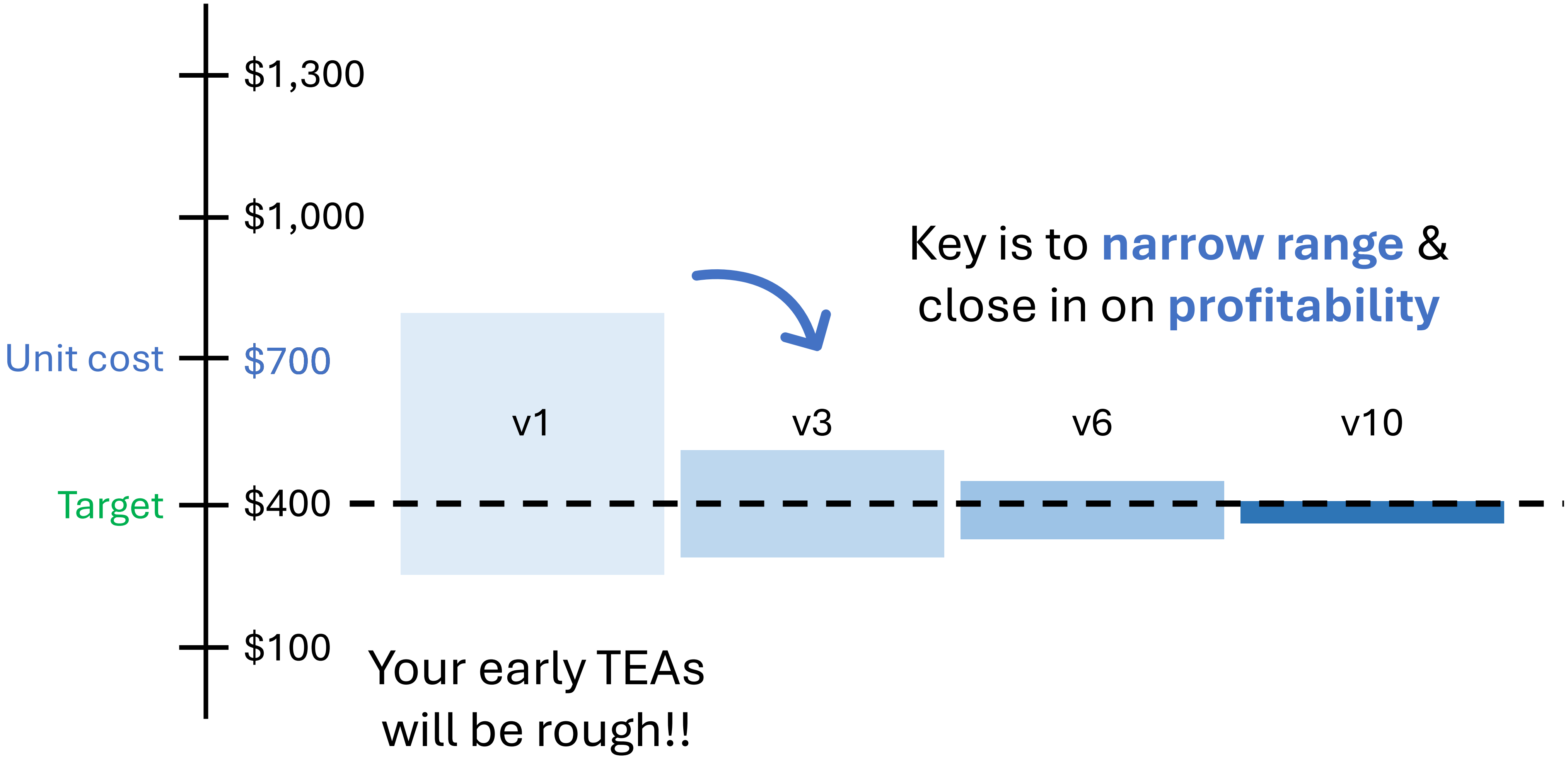
Don’t bet the farm on drivers you can’t control

Collect data & validate biggest bets first to **narrow uncertainty range**

Triple check & **deprioritize drivers** that don’t move the needle

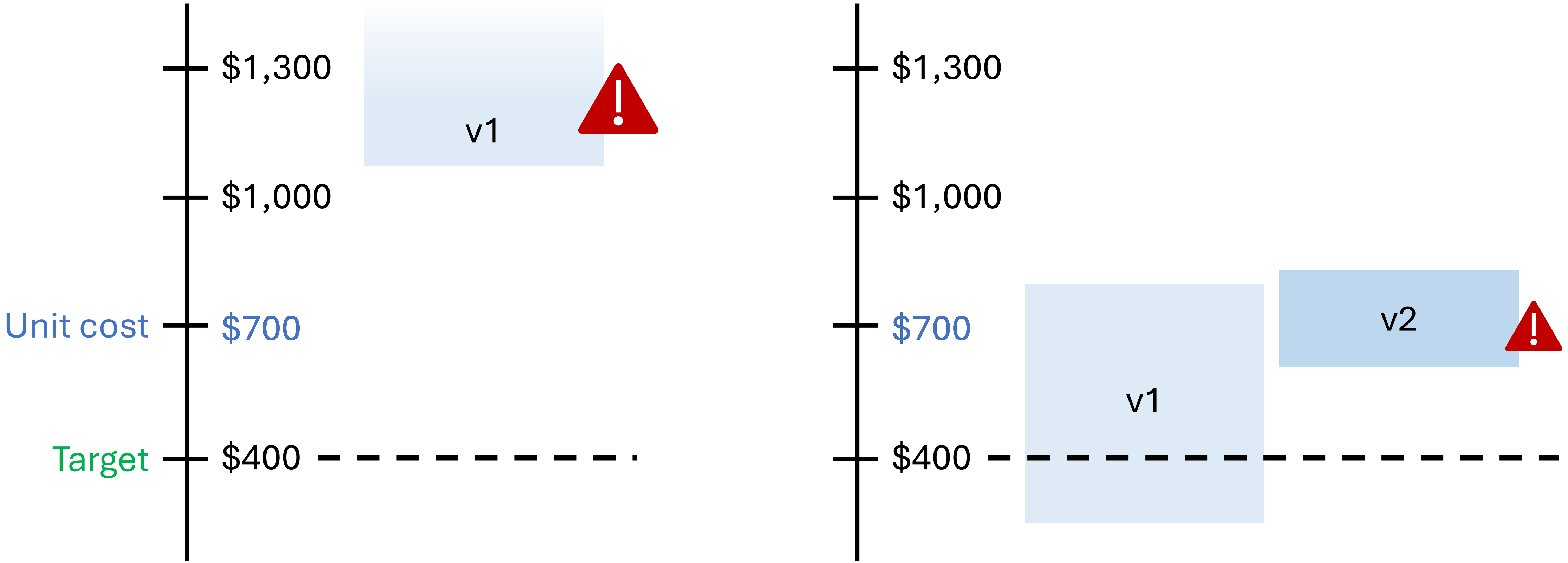
The mental model

Get started & religiously iterate



The mental model

Otherwise, how would you know where you land?



Estimate feasibility **early and often** to avoid costly mistakes and course correct!

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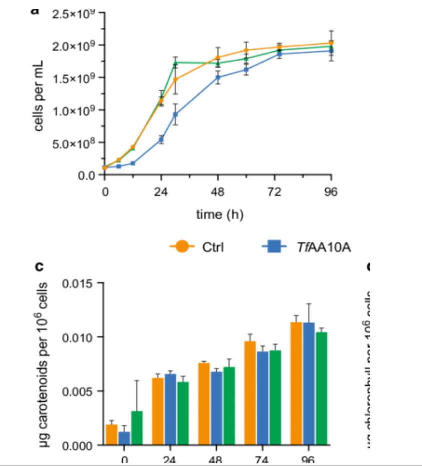
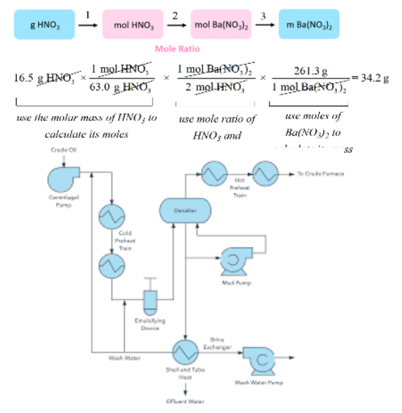
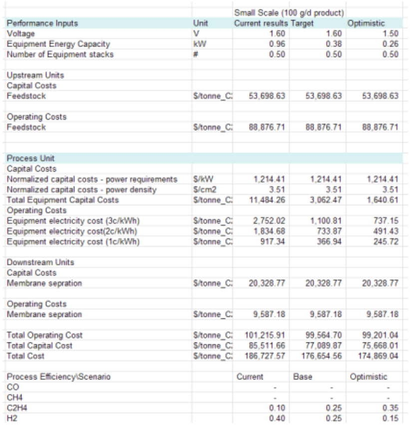
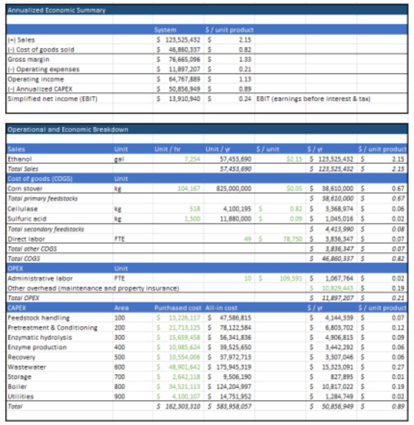
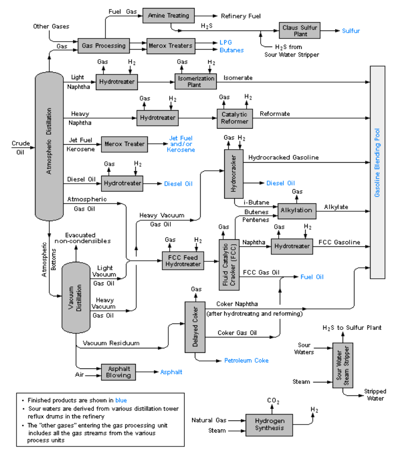
Today's agenda

Why do you need a TEA?	15min	• Let's build the mental model first! • TEA = Analytical foundation for your company
What does good look like?	15min	• TEA for early stage comes in different sizes • Building trust in your model
How do you build one?	20min	• The steps to get started • Walking through an example
Now what?	5min	• Some resources & frameworks • Reach out if you're interested in help with TEA!

Poll: Where are you on your TEA journey?

Published research & data, no TEA	Rough process flow, "napkin math"	Simple TEA on 1 Excel sheet	TEA with some depth & analytics	Complex TEA (Excel, Aspen)
				

Increasing complexity

QR Code links to Google Forms: https://forms.gle/KRcmCf4arvA9TBU26 (same form)

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Poll: How often do you update your TEA?

Yearly

Quarterly

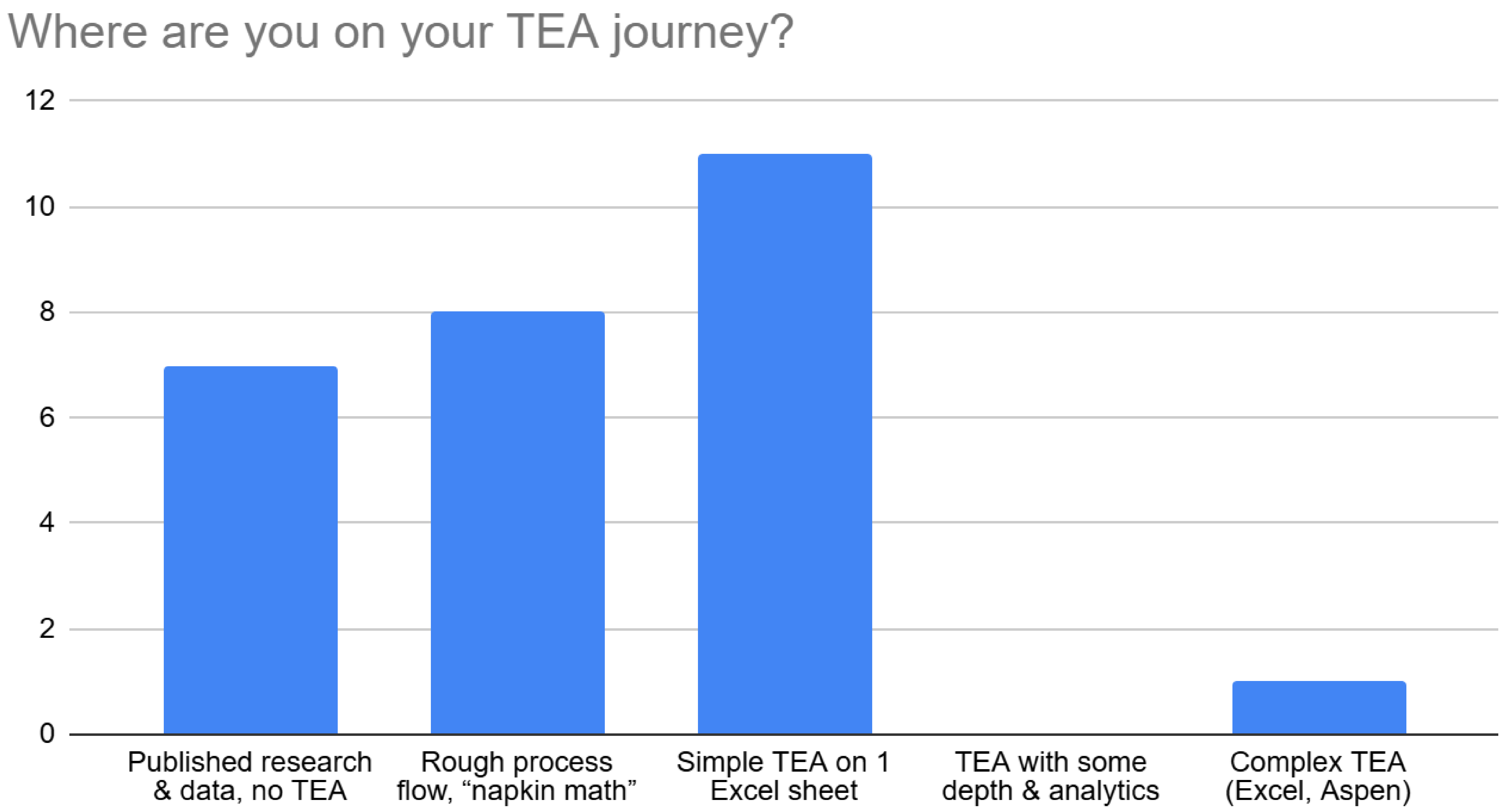
Monthly

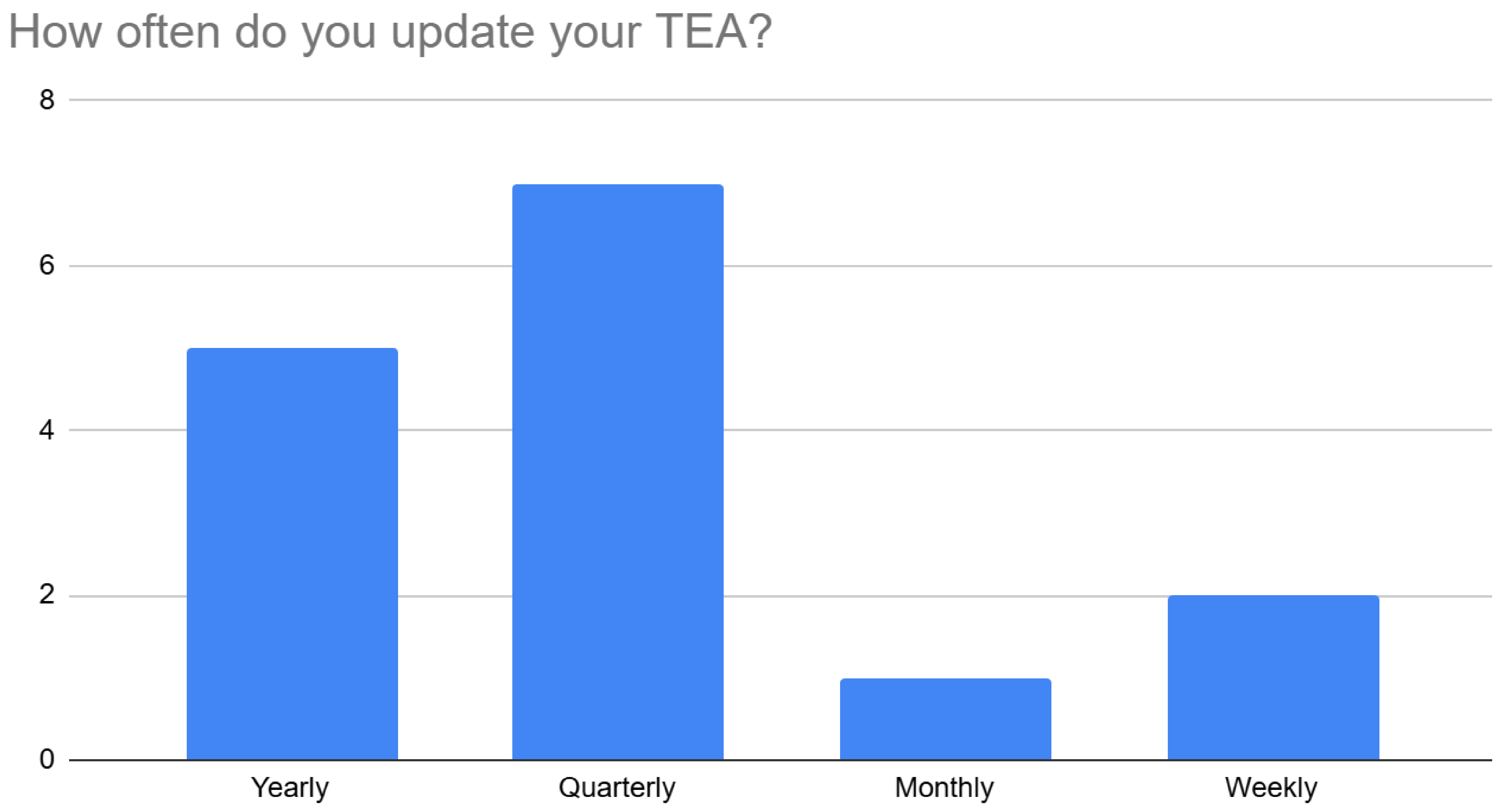
Weekly

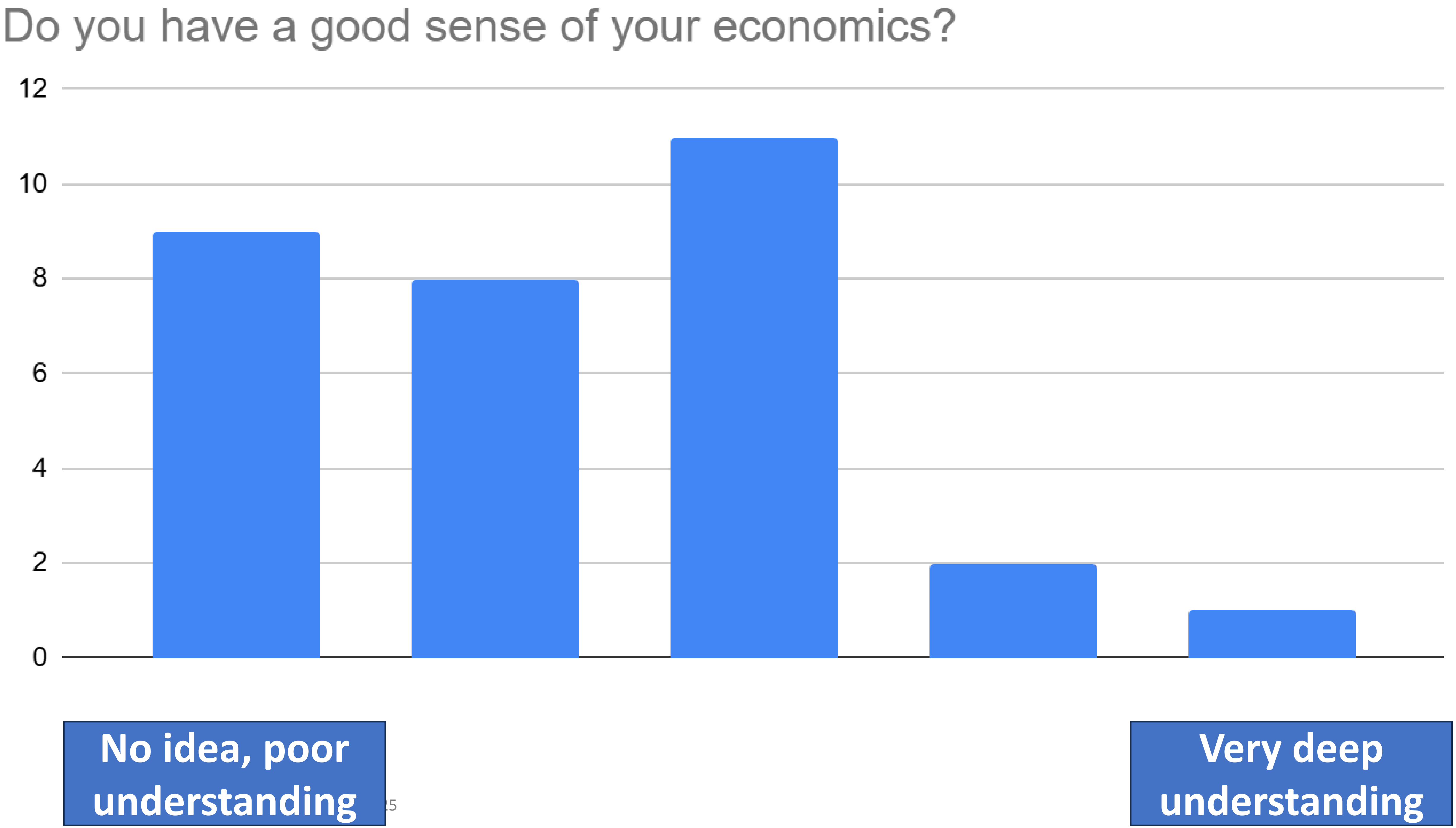
QR Code links to Google Forms: https://forms.gle/KRcmCf4arvA9TBU26 (same form)

Poll: Do you feel like you have a good mental model around your company's long-term economics?

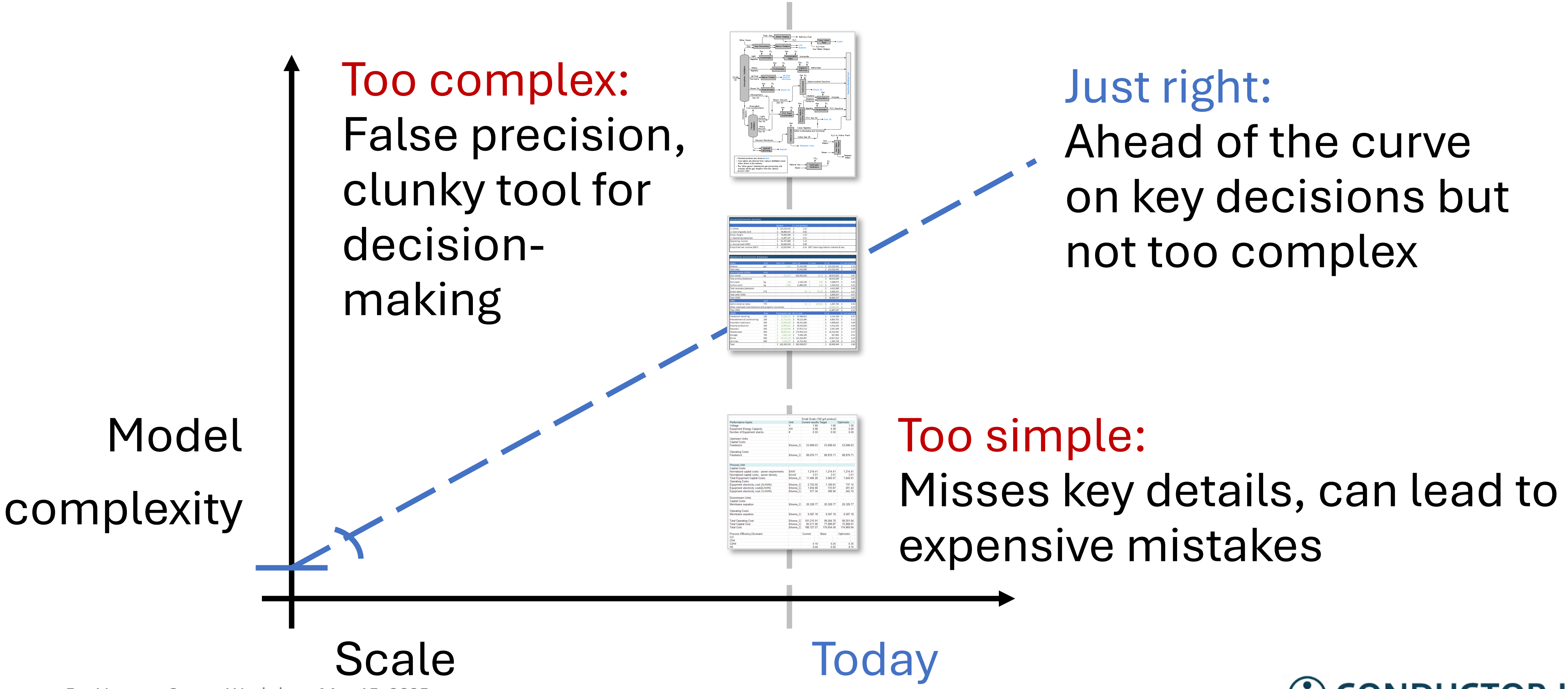
QR Code links to Google Forms: https://forms.gle/KRcmCf4arvA9TBU26 (same form)


Where are you on your TEA journey?
12
10
8
6
4
2
0
Published research & data, no TEA
Rough process flow, "napkin math"
Simple TEA on 1 Excel sheet
TEA with some depth & analytics
Complex TEA (Excel, Aspen)


How often do you update your TEA?
8
6
4
2
0
Yearly
Quarterly
Monthly
Weekly

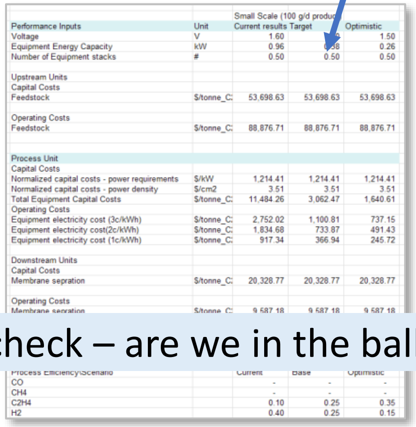

Do you have a good sense of your economics?
12
10
8
6
4
2
0
No idea, poor understanding
Very deep understanding

Right-sizing **your** TEA is half the battle

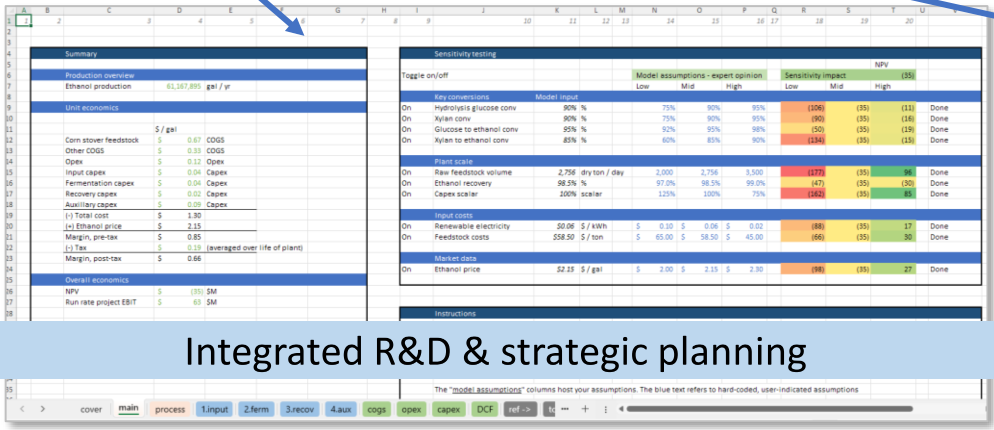


“TEA-Readiness-Level” can help guide you

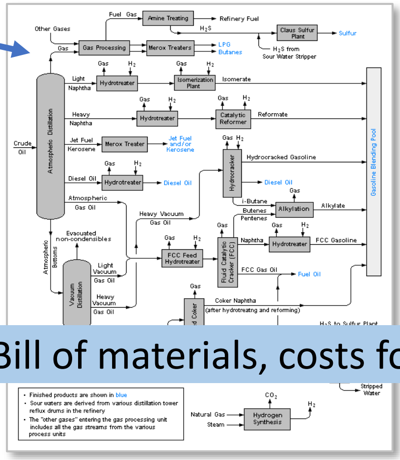
Te-RL	0-1	2-3	4-5	6-7	8-9
Technology scale	Conceptual idea	Lab scale	Pre-pilot scale	Pilot	Small demo
What it looks like	Excel: 1-2 sheets, simple process flow	Excel: 4-5 sheets, detailed process flow, sensitivities	Complex excel model for strategic planning AspenPlus for pilot design	AspenPlus: Detailed assumptions, real-world data, location specific	Industrial controls systems & planning feeding financial / operational models
Approximate effort	15 hr	75 hr	250 hr	1,000 hr+	3,000 hr+



Gut check – are we in the ballpark



Integrated R&D & strategic planning



Bill of materials, costs for EPC

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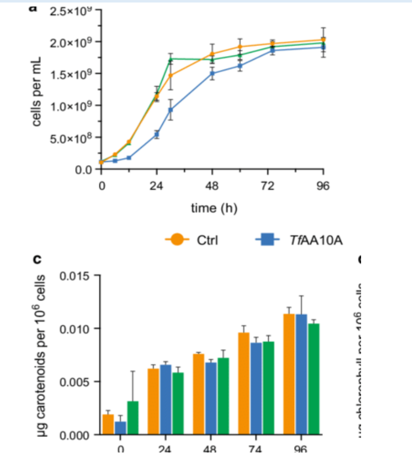
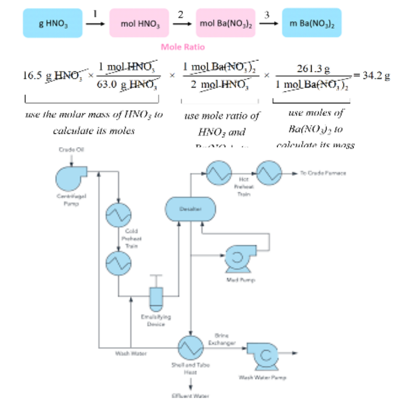
Almost all teams start in one of these boxes

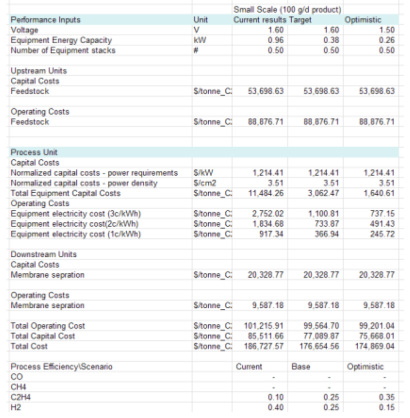
Published research & data, no TEA



Rough process flow, "napkin math"

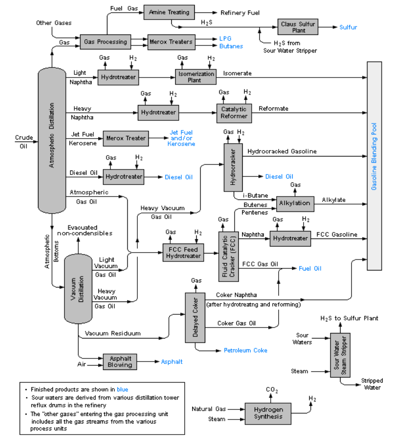


Simple TEA on 1 Excel sheet



TEA with some depth & analytics

Complex TEA (Excel, Aspen)



Initial goal to build a baseline model with:

- Your core technology mapped out
- End-to-end flow
- Mass and/or energy balance
- Referenceable assumptions
- Simple sensitivities

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Baseline model: End-to-end flow

Start with process flow's feedstocks

Account for big waste streams

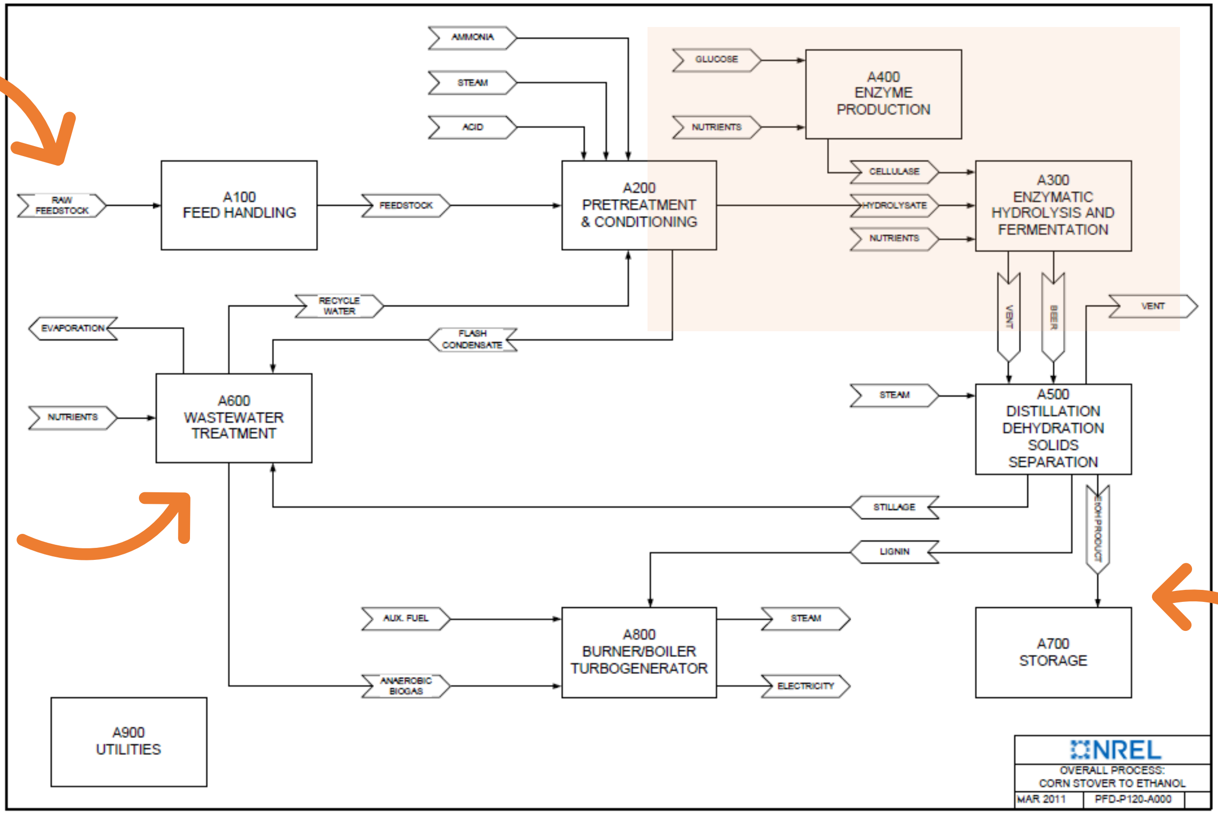


Figure 1. Simplified flow diagram of the overall process, PFD-P120-A000

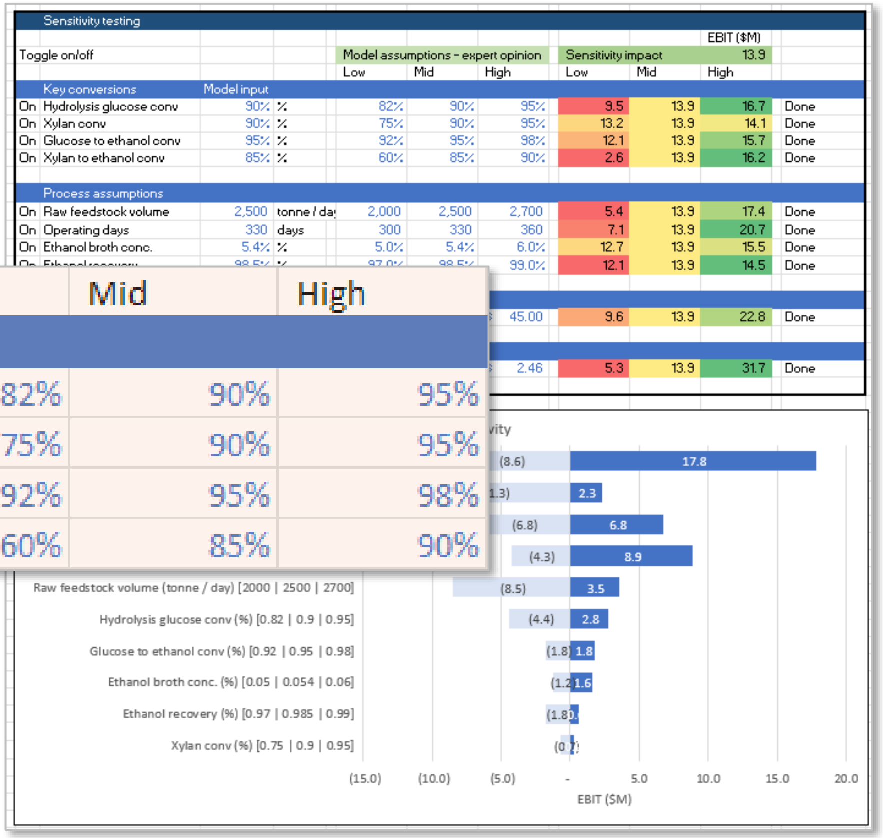
Your **Core Tech**

End with the sellable product

Baseline model: Simple sensitivities

Some way to toggle between **different assumptions**

			Low	Mid	High
Key conversions	**Model input**				
Hydrolysis glucose conv	90%	%	82%	90%	95%
Xylan conv	90%	%	75%	90%	95%
Glucose to ethanol conv	95%	%	92%	95%	98%
Xylan to ethanol conv	85%	%	60%	85%	90%



And see the **resulting impact** on economics

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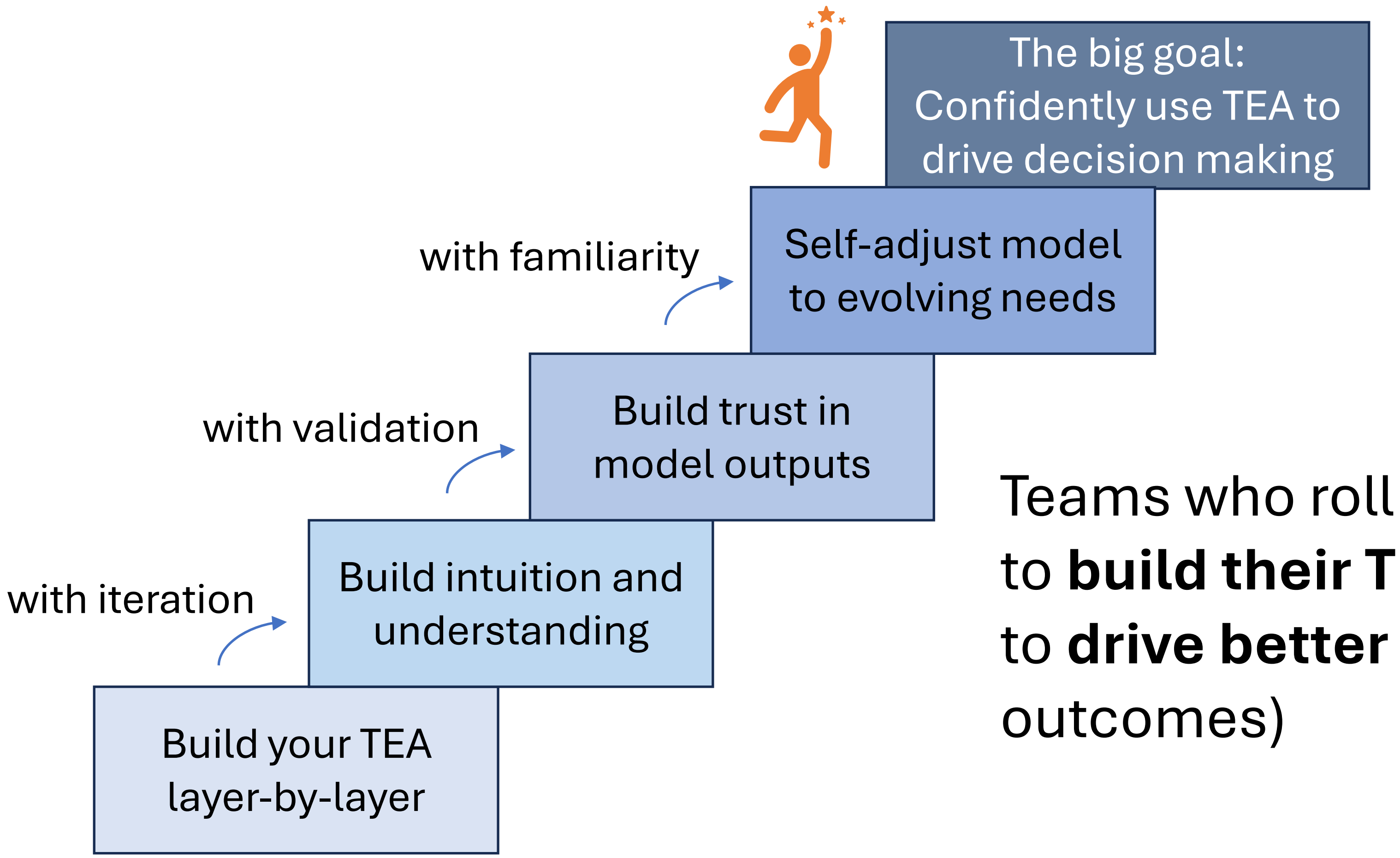
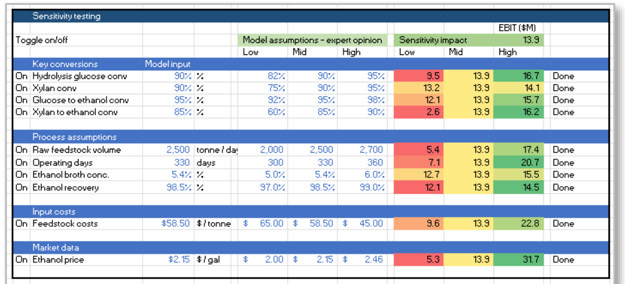
My observations from working with dozens of teams



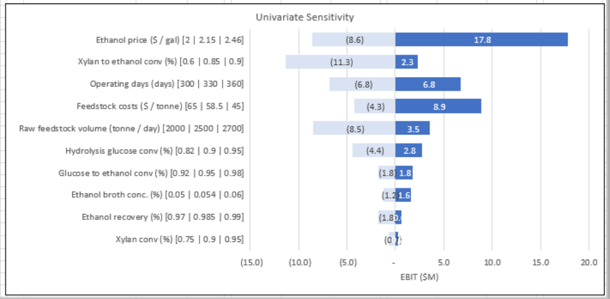
Teams who roll up their sleeves to **build their TEA** end up using it to **drive better decisions** (and outcomes)

What VCs are looking for in your TEA

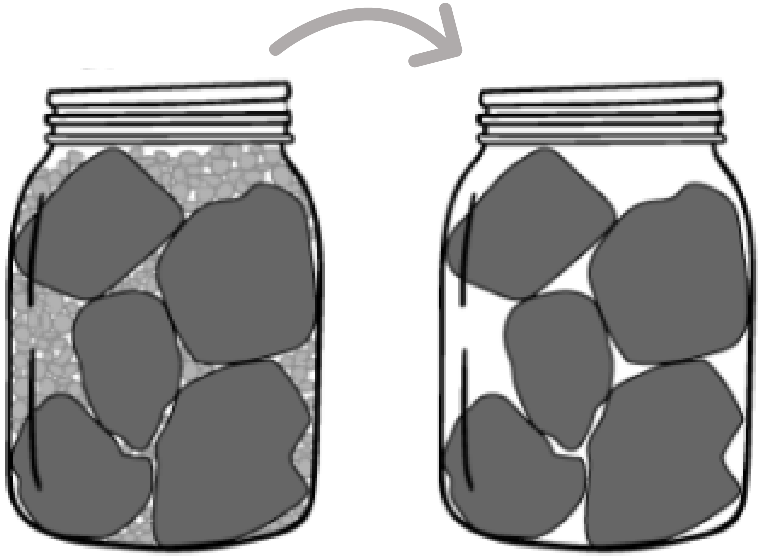
Your model



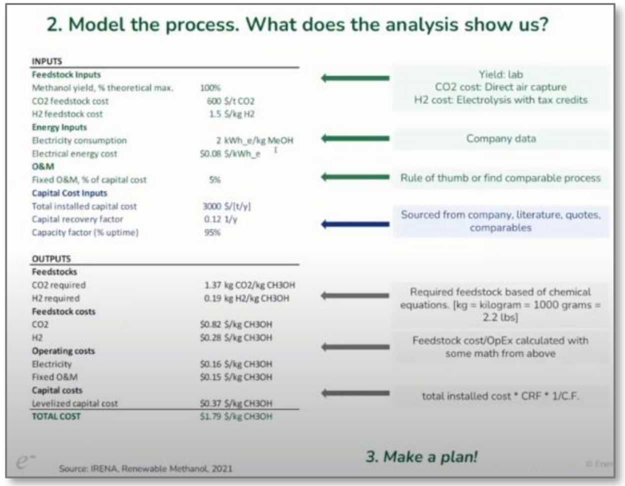
	Sensitivity testing									
								EBIT ($M)		
Toggle on/off				Model assumptions – expert opinion			Sensitivity impact		13.9	
				Low	Mid	High	Low	Mid	High	
	Key conversions	Model input								
On	Hydrolysis glucose conv	90%	%	82%	90%	95%	9.5	13.9	16.7	Done
On	Xylan conv	90%	%	75%	90%	95%	13.2	13.9	14.1	Done
On	Glucose to ethanol conv	95%	%	92%	95%	98%	12.1	13.9	15.7	Done
On	Xylan to ethanol conv	85%	%	60%	85%	90%	2.6	13.9	16.2	Done
	Process assumptions									
On	Raw feedstock volume	2,500	tonne / day	2,000	2,500	2,700	5.4	13.9	17.4	Done
On	Operating days	330	days	300	330	360	7.1	13.9	20.7	Done
On	Ethanol broth conc.	5.4%	%	5.0%	5.4%	6.0%	12.7	13.9	15.5	Done
On	Ethanol recovery	98.5%	%	97.0%	98.5%	99.0%	12.1	13.9	14.5	Done
	Input costs									
On	Feedstock costs	$58.50	$ / tonne	$ 65.00	$ 58.50	$ 45.00	9.6	13.9	22.8	Done
	Market data									
On	Ethanol price	$2.15	$ / gal	$ 2.00	$ 2.15	$ 2.46	5.3	13.9	31.7	Done



Detailed model to drive decisions AND build conviction



EIP's "10-liner" TEA



What are the **7-10 "big rocks"** that can help proxy **"can I believe this?"**

SOSV Summit: EIP: Why Climate Tech Startups Need Techno-Economic Analysis (@ 13:30 ish), also Catalyst has a great podcast on TEA
Mindful Ambition: jar of rocks

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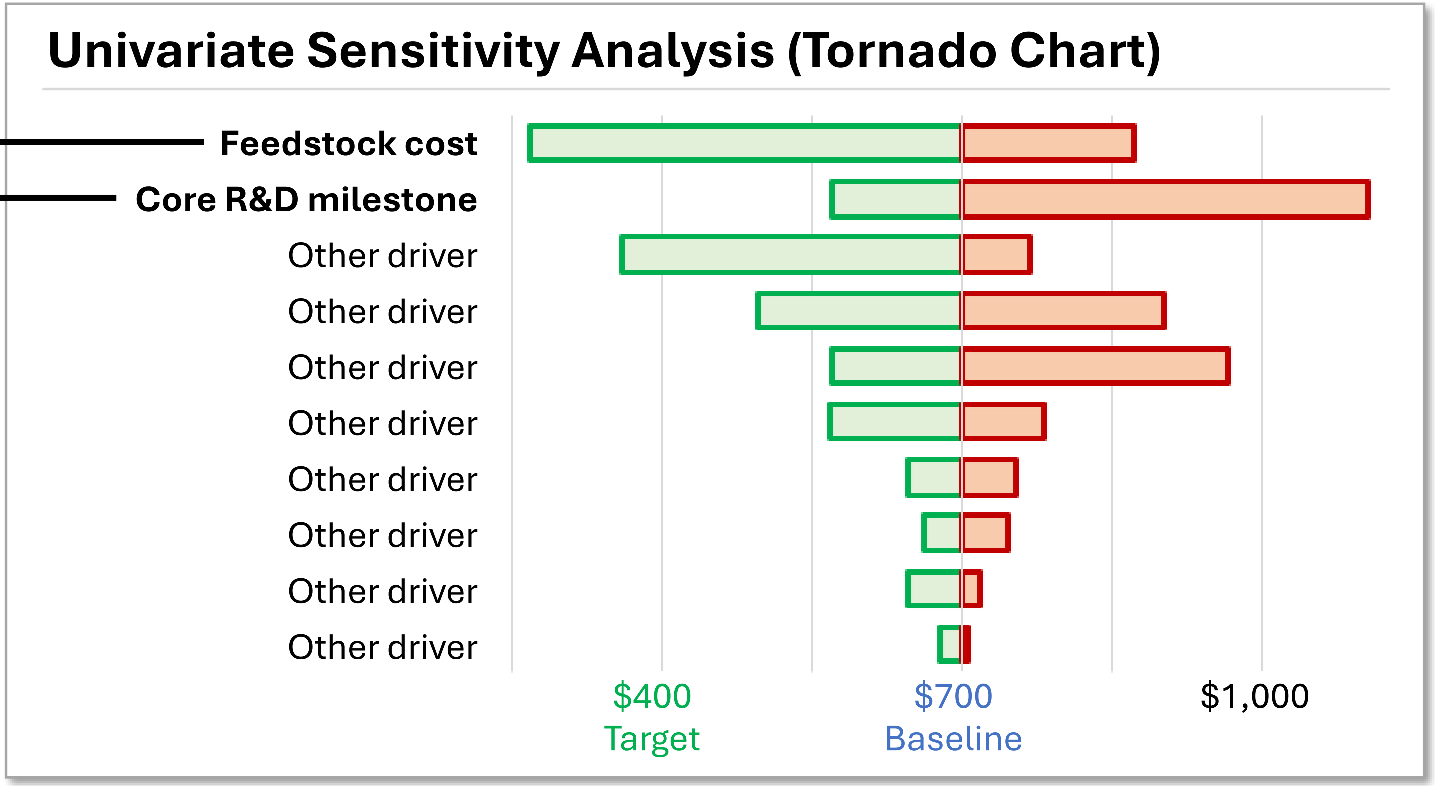
What VCs are looking for in your TEA

Do I want to sign up for this bet?

Is the impact of team's core tech gamechanging?

Many VCs will ask for it, but that's not **why** you should have one!



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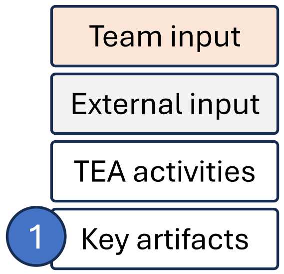
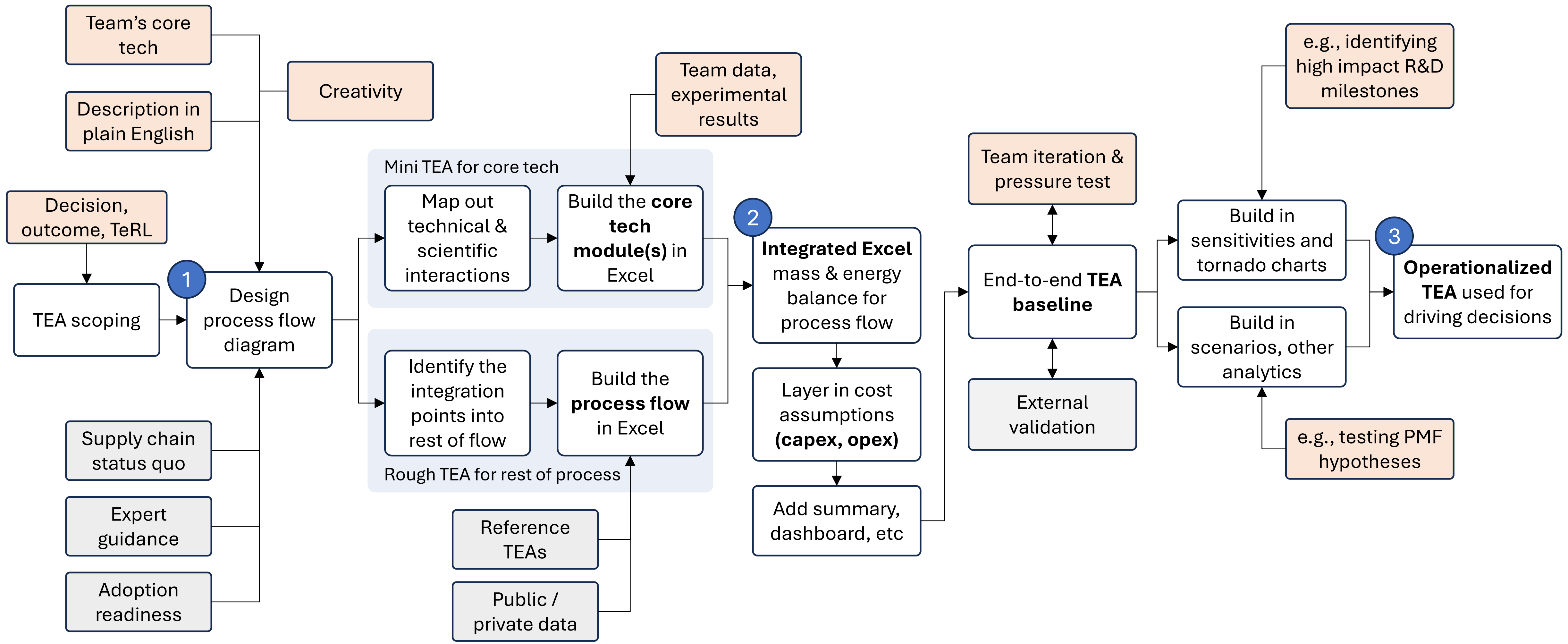
Today's agenda

Why do you need a TEA?	15min	• Let's build the mental model first! • TEA = Analytical foundation for your company
What does good look like?	15min	• TEA for early stage comes in different sizes • Building trust in your model
How do you build one?	20min	• The steps to get started • Walking through an example
Now what?	5min	• Some resources & frameworks • Reach out if you're interested in help with TEA!



The TEA for your TEA



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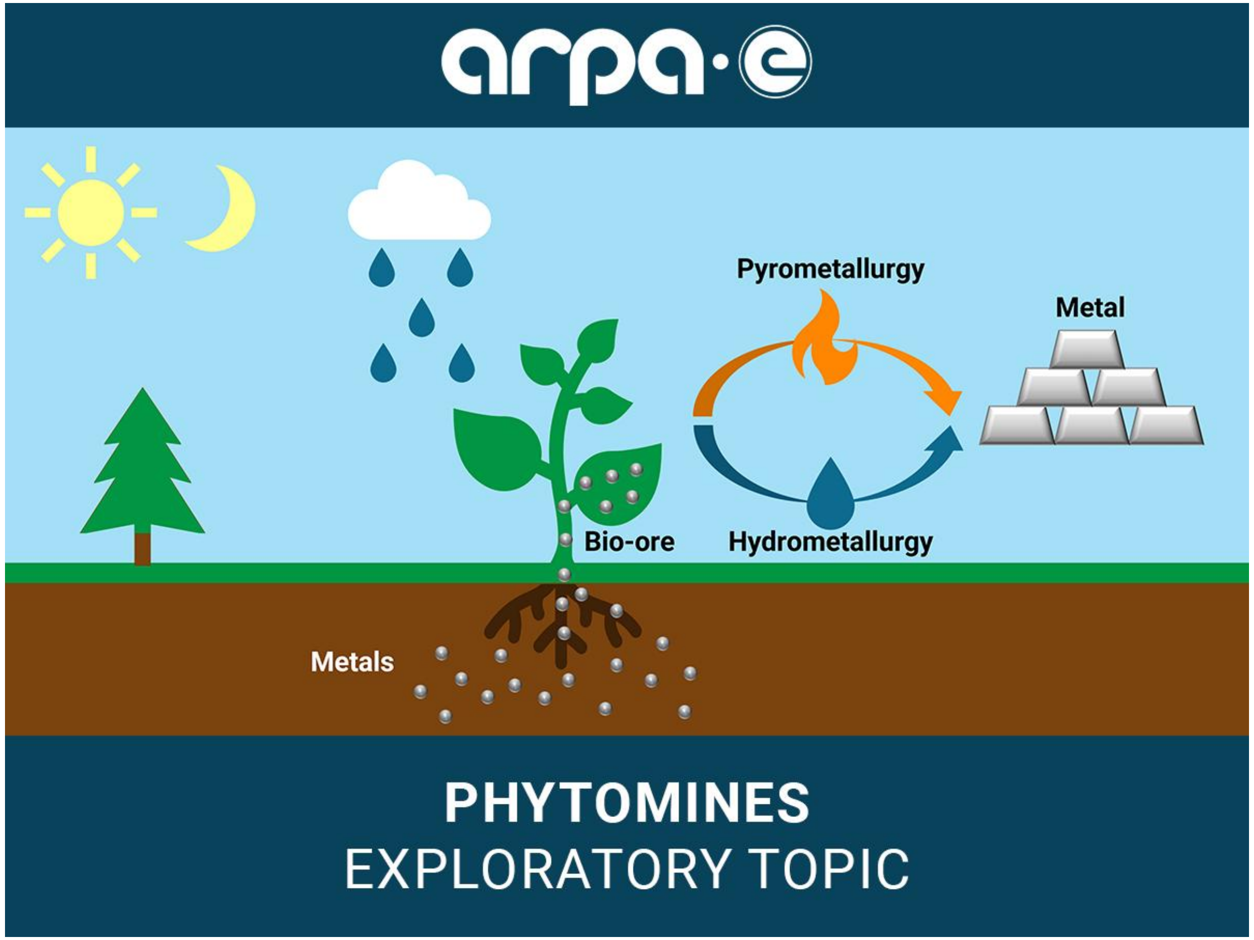
Let’s mine some metal with plants



ARPA-E press release

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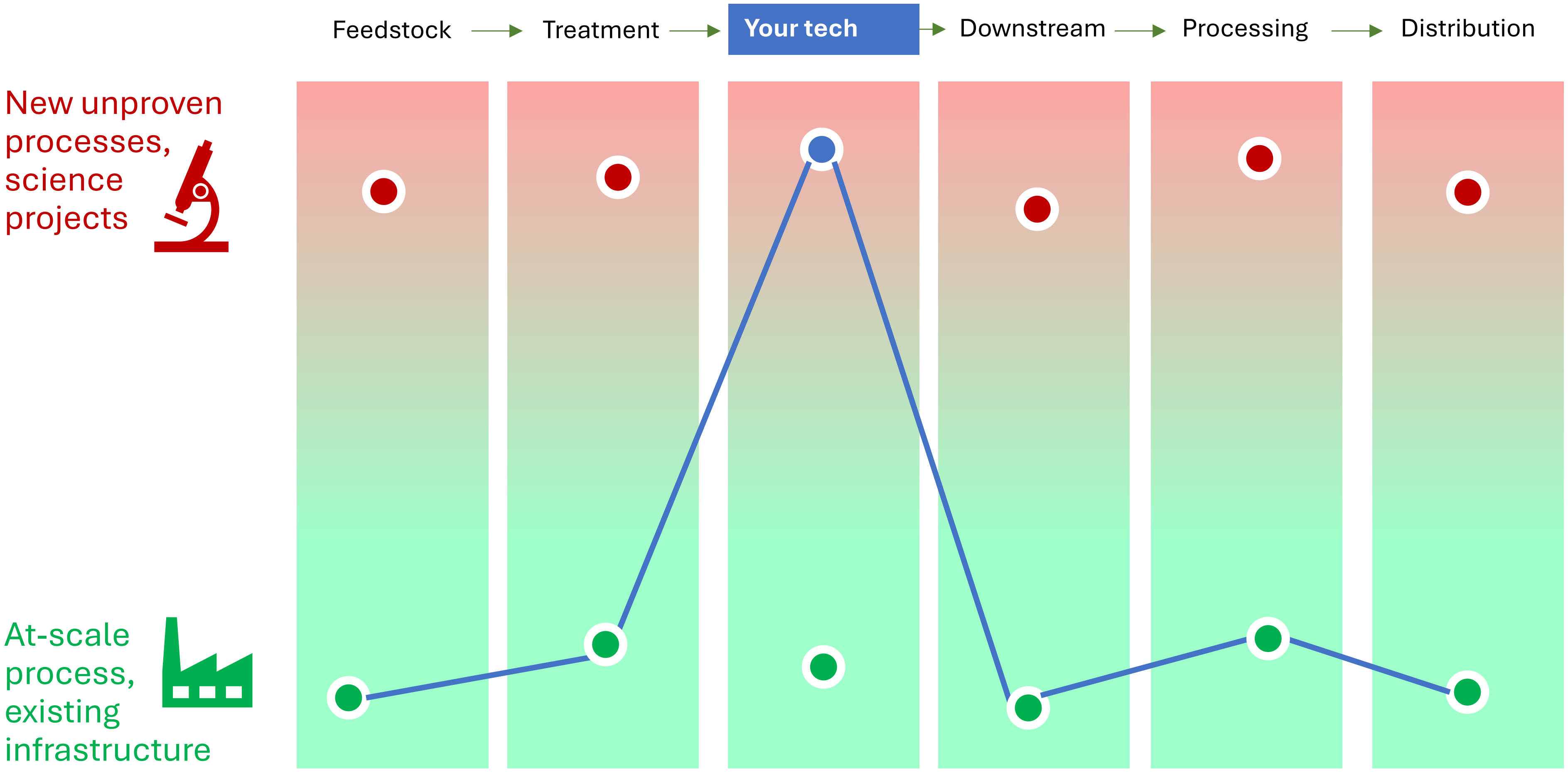
First start with scoping

Objectives	• What decisions are you looking to drive? (set R&D milestones) • What criteria are you using to make that decision? (technical feasibility, unit economic impact)	The why
Hypotheses	• What are considerations around pre-treatment decision? • Where are there major sensitivities? • What types of scenario testing would be interesting?	The what (structure, skeleton)
System boundary	• How far upstream? Downstream? • How deep to go in each?	The what (structure, skeleton)
Scale	• Size (usually at commercial scale) • Time frame	The what (structure, skeleton)
Level of detail	• Depth of analysis, assumptions • What is 'good enough'?	The what (structure, skeleton)
Deliverable	• Timeline • Functionality	The how (filling in the structure)
Success criteria	• Ownership?	The how (filling in the structure)

Process flow design

Adoption readiness: easier to deploy or higher performance?



- Minimize the number of “miracles”
- Don’t count on assumptions from other start-ups or cutting edge research

- Deploy into existing infrastructure & supply chains!
- Less risk, more buy-in, more data available

[“Can we build AND scale it?”](#) by B Capital & US DOE’s [Adoption Readiness Levels (ARL)](#) are helpful reads

Process flow design

v1: Explain it Like I'm 5-years-old (ELI5)

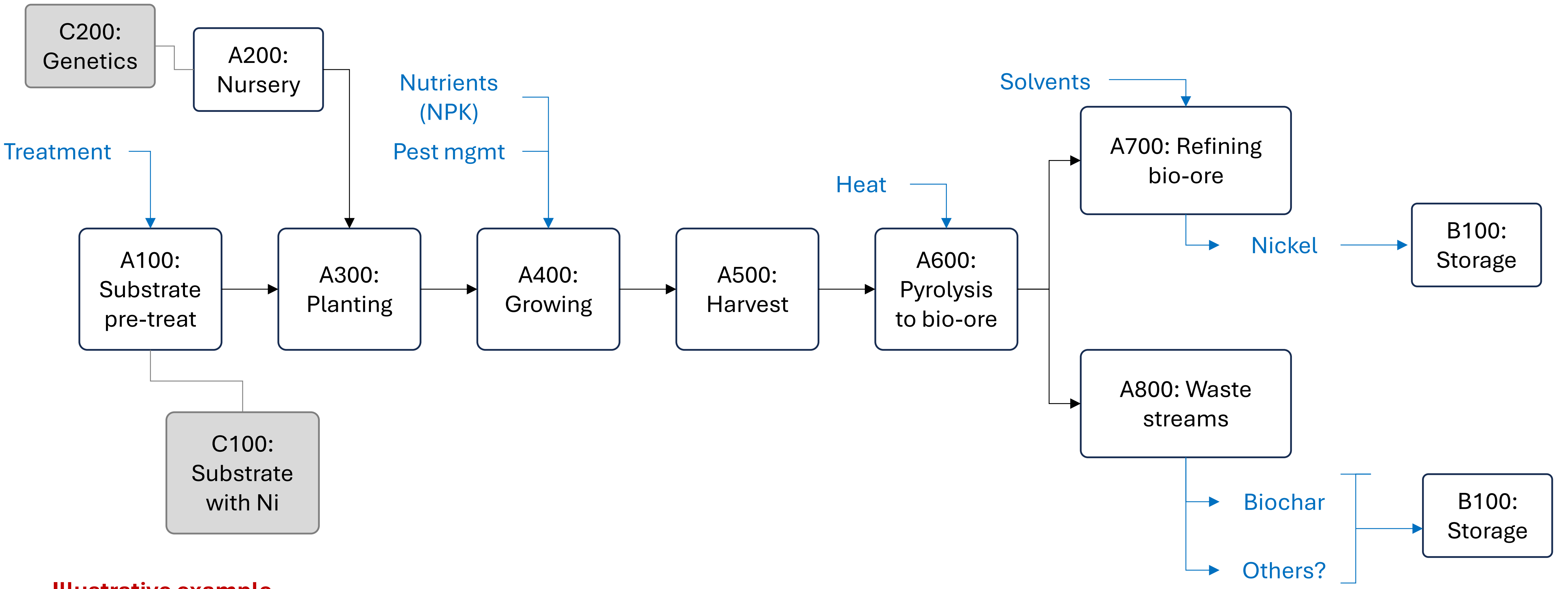
Grow some plants in Ni rich soil → Collect the berries → Extract the metals from biomass → Sell the metals

Illustrative example

Images from Unsplash

Process flow design

v2: Finding the right amount of complexity



Illustrative example

Process flow design

v3: Iterating on the process flow

How detailed to break down?

More depth?

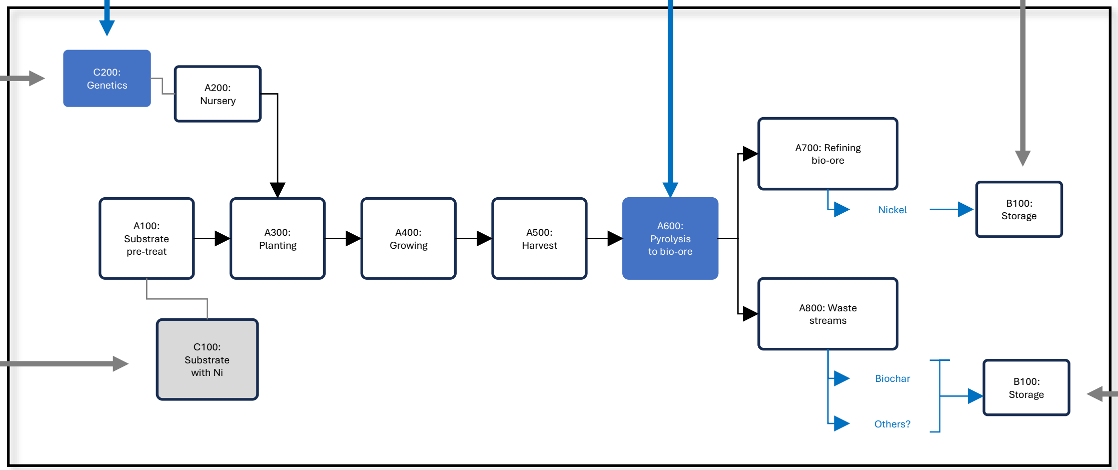
Your core technology

Product grade?

What are the core feedstocks?

Transportation?

Other products?



Pre-treatment?

Downstream processing?

Waste management?

Map out technical & scientific interactions

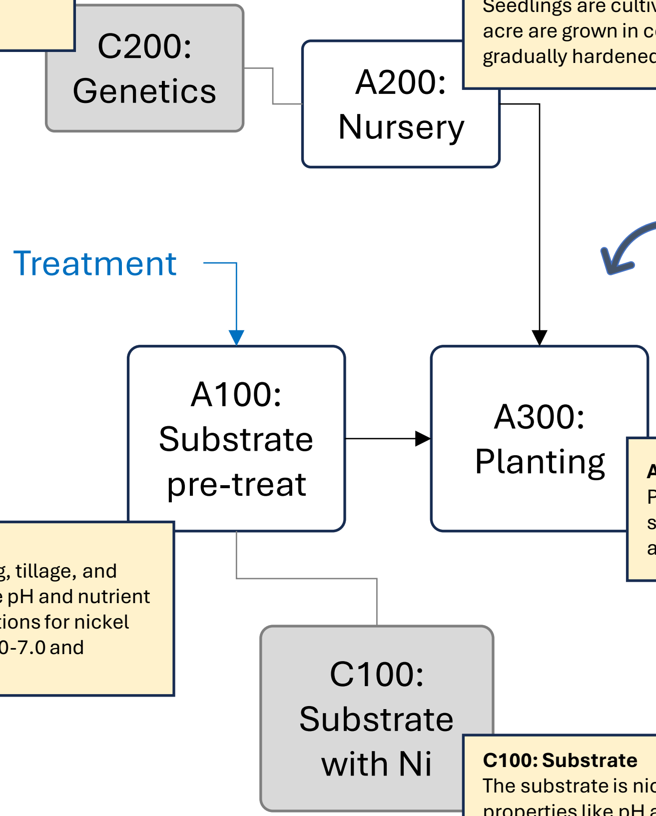
When in doubt, write it out

Start by just describing the process in words and numbers...

C200: Genetics
The core innovation focuses on optimizing plants for nickel hyperaccumulation, aiming for 0.02 kg Ni uptake per kg of plant biomass, with 90% distributed to berry biomass.

A200: Nursery
Seedlings are cultivated over 4-8 weeks. 50,000 seedlings per acre are grown in controlled environments before being gradually hardened for outdoor conditions.

...then map them to boxes & arrows



A300: Planting
Plant seedlings at a density of 50,000 plants / acre, with 0.5m spacing between plants. Process requires ~0.2 labor hours / acre using industrial scale agriculture equipment.

A100: Substrate pre-treat
Soil preparation involves comprehensive testing, tillage, and amendment with lime and fertilizers to optimize pH and nutrient levels. The goal is to create ideal growing conditions for nickel hyperaccumulator plants, with a target pH of 6.0-7.0 and balanced nutrient content.

C100: Substrate
The substrate is nickel-contaminated soil, which needs to be characterized for its nickel content, depth, and other properties like pH and nutrient levels. Preparation involves tillage to an appropriate depth for the hyperaccumulator plants' root systems, along with any necessary amendments to optimize growing conditions for maximum nickel uptake.

Illustrative example

Map out technical & scientific interactions

Connect the words & numbers to formulas

To estimate the amount of Nickel I can recover per acre, I need to estimate how many kg of berries I'll be able to harvest from my plants, and assuming some uptake rate, can estimate the total Nickel.

$$\frac{berries\ (kg)}{acre} * \frac{Nickel\ (g)}{berries\ (kg)} = \frac{Nickel\ (g)}{acre}$$

Excel is just a way to record the "stoichiometry"

$$\frac{Nickel\ (g)}{acre} * \frac{\$}{Nickel\ (g)} = \frac{\$}{acre}$$

Once I know how much Nickel I can recover per acre, I can multiply it by the price per gram of Nickel at market value to estimate an upper bound of value per acre.

Substrate	C100	
Acre	4,047	m2
Root depth	0.1	m
Soil volume	405	m^3
Loam	1.3	g / cm^3
	1,330	kg / m^3
Soil wt / acre	538,251	kg
Ni concentration	2%	
Availability in topsoil	95%	
Ni available	10,227	kg / acre
Genetics	C200	
Root depth	0.1	m
Density (1 plant per unit area)	0.25	m^2
Number of plants per acre	16,188	plants / acre
ass per plant	0.5	kg per plant at harvest
plant biomass	8,094	kg biomass / acre
e of Ni	0.02	kg / kg plant
Ni uptaken into plant	162	kg Ni / acre
innovation		
biomass per plant	0.11	kg / kg plant
berry biomass	890	kg berry biomass
tribution into berry biomass	90%	
Ni in berry biomass for reco	146	kg Ni / acre in berry biomass
Density of Ni in berry biomass	0.16	kg Ni / kg berry biomass

Illustrative example

Start with simplified financials

Line item	Category	Examples & notes
(+) Sales	Sales	Number of tonne Ni * $ / tonne Ni = $ sales
(-) Cost of goods sold (COGS)	Variable costs	Costs that scale directly with sales (seeds, soil fertility, solvents, hourly labor)
= Gross profit		At its core – is your tech/business profitable?
(-) Operational expenses (OPEX)	Variable costs	Costs that generally scale with sales but not directly (administrative labor, maintenance costs, power if it's not directly related to products)
(-) Annualized capital expenses (CAPEX)	Capital costs	Buildings (greenhouses, smelters) Equipment (tractors, reactors)
= Net income		Simplified profitability metric; ignores tax, interest payments, and other strategic finance levers

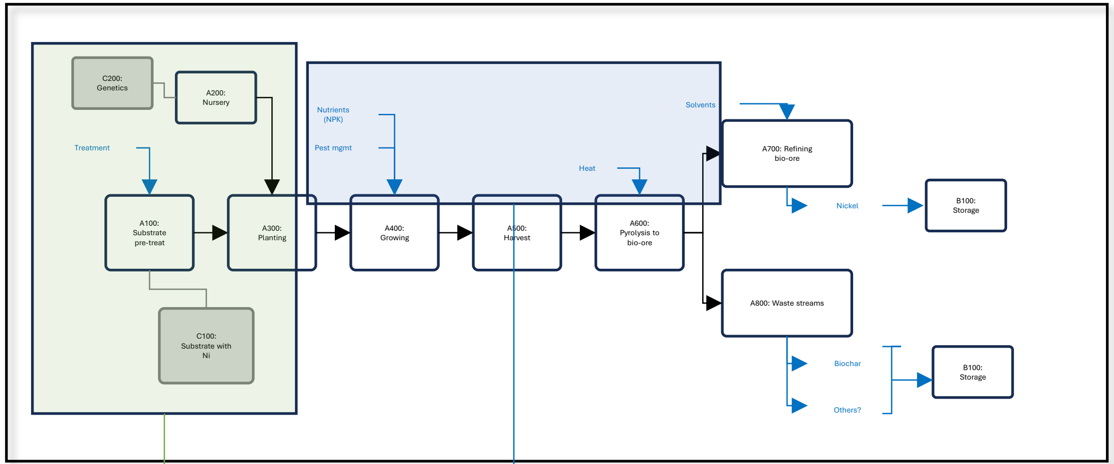
If you're early on, focus on big picture economics to make sure you're in the ballpark. Then get more detailed.

Costs: capital costs & variable costs

Capital costs

For each unit operation:
- Buildings
- Equipment

Find references for:
- Equipment costs & their sizing (volume, flow-rate, etc)



Variable costs

Across the flow, track:
- Feedstock
- Other auxiliary inputs
- Waste streams

Find references for:
- Loading rates (how much X input per Y flow)
- Unit costs for each

Calculating Annualized CAPEX*
1. Right-size each of the equipment (six-tenths rule)
2. Sum up all of the equipment and account for indirect costs
3. Annualize using capital recovery factor equation

Calc. Cost of goods sold (COGS)
1. Track flow-rates through your system on hourly or daily basis
2. Multiple flow-rates by unit costs
3. Annualize these costs

Calc. Operational expenses (OPEX)
1. Labor – account for benefits & overhead as needed
2. Other overhead (maintenance, insurance) – find industry refs
3. Shouldn't be a big driver of costs (not where you're innovating)

* See appendix for more details on capex calculations

Assumptions make-or-break your TEA

Teams	Investors, Stakeholders	Partners, Customers

More **optimistic** assumptions ← → More **conservative** assumptions

Nickel Price ($ / tonne), ycharts

Selling nickel at **$20-25k / tonne**?

vs **$10-15k / tonne**?

Energy Impact Partners' [Catalyst Podcast on TEA] is great on this

Then iterate!

Build the rest of the model & iterate

	Flow rates	$ / unit	Unit / acre / yr	$ / acre / yr
	Nickel production (kg)	$ 17.85	140	$2,498
	Biochar (kg)	$ 1.00	327	$327
		opex	deprec.	% of total
A100	Substrate pre-treatment	$ 30.00	$ 40.00	4%
A200	Nursery (seedlings, etc)	$ 115.36	$ 50.00	9%
A300	Planting	$ -	$ -	0% opex assur
A400	Growing	$ 230.99	$ 35.00	15%
A500	Harvest	$ 56.80	$ 30.00	5%
A600	Convert to bio-ore	$ 327.60	$ 351.00	38%
A700	Refining bio-ore	$ 151.75	$ 280.80	24%
A800	Waste streams	$ 65.33	$ 24.50	5%
B100	Storage	$ -	$ 50.00	3%
	Sub-totals	$ 977.82	$ 811.29	100%
	Total cost	$ 1,789.12		
	Revenues	$ 2,824.52		
	Gross margin	$1,035.40		

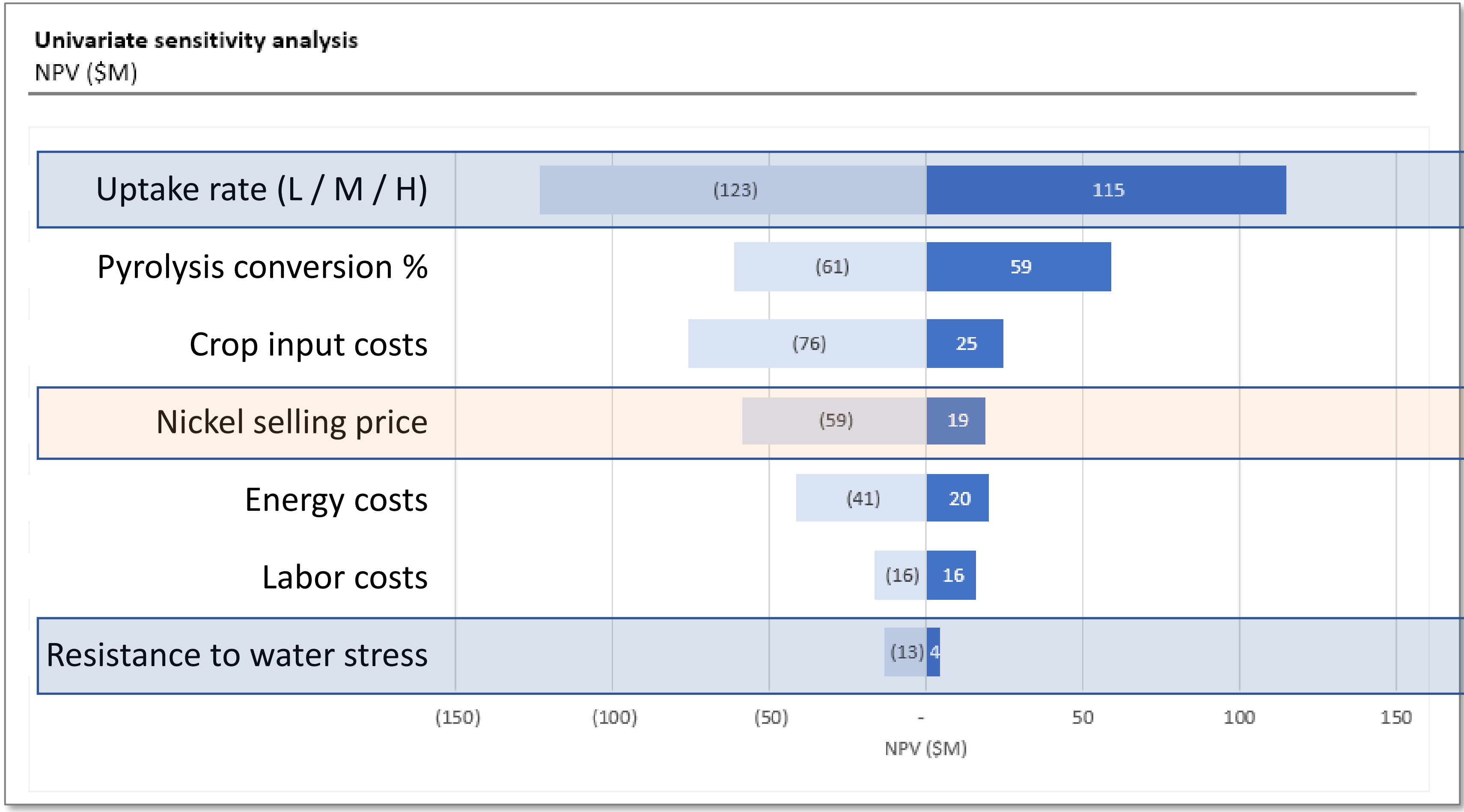
Reflecting & iterating on:

- Target the high % numbers first
- Revenues: How does mining volume change over time?
- Where does biology factor into economics?
- How do you build intuition around your process?

Illustrative example: numbers intentionally chosen for discussion only

Then iterate!

Then drive decisions... then keep iterating!!



Within your control, **high impact**

→ Invest energy into this, validate further

Not in your control

→ Mitigate via R&D, more targeted market exploration

Within your control, **low impact**

→ Deprioritize?

Illustrative example: numbers intentionally chosen for discussion only

Today's agenda

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How do you build one?	20min	• The steps to get started • Walking through an example
Now what?	5min	• Some resources & frameworks • Reach out if you're interested in help with TEA!

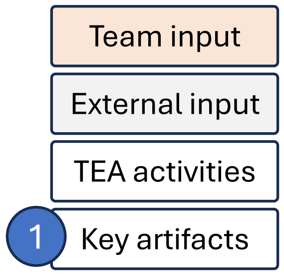
My takeaways for you

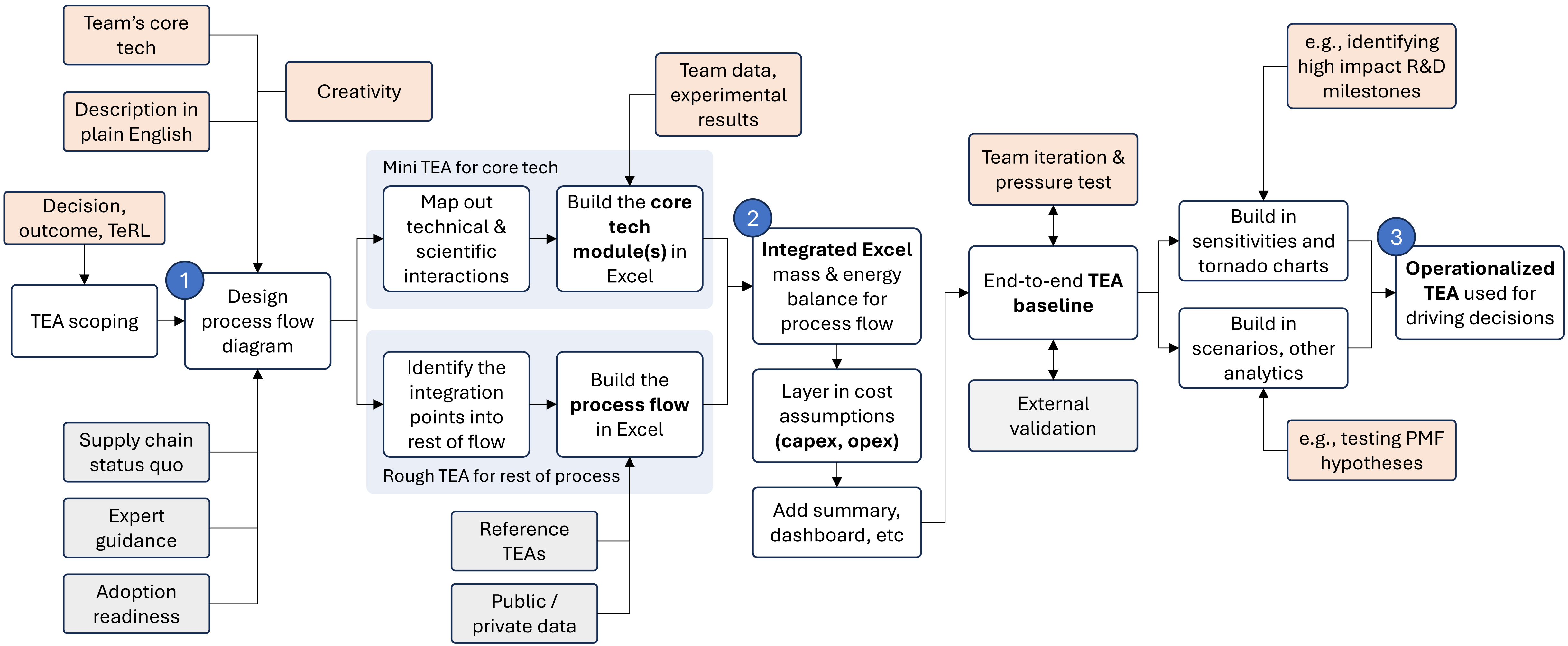
1. **Start simple, then iterate** – focus on breadth, then depth. Mass balance first, then layer in costs.
2. **Choose thoughtful assumptions** – once you have a TEA, the feedback loop is all about a) refining assumptions, b) seeing how things shake out, and then c) iterating.
3. TEA is **too mission critical to outsource** – you must build your own intuition, even if it's rough. Then hire someone.

Conductor's **mission**: Helping climate founders achieve these goals!

Resources

The TEA for your TEA





Resources

Some examples of other resources

TEA templates:
We recommend building your TEAs from the ground up, and use templates as a rough guide of what good looks like
- Activate (www.activate.org/techonomics)
- AssessCCUS (https://assessccus.globalco2initiative.org/tea/templates-and-videos/)
- Planet A (https://planet-a.medium.com/a-simple-founders-guide-to-teas-b469f423a2db)

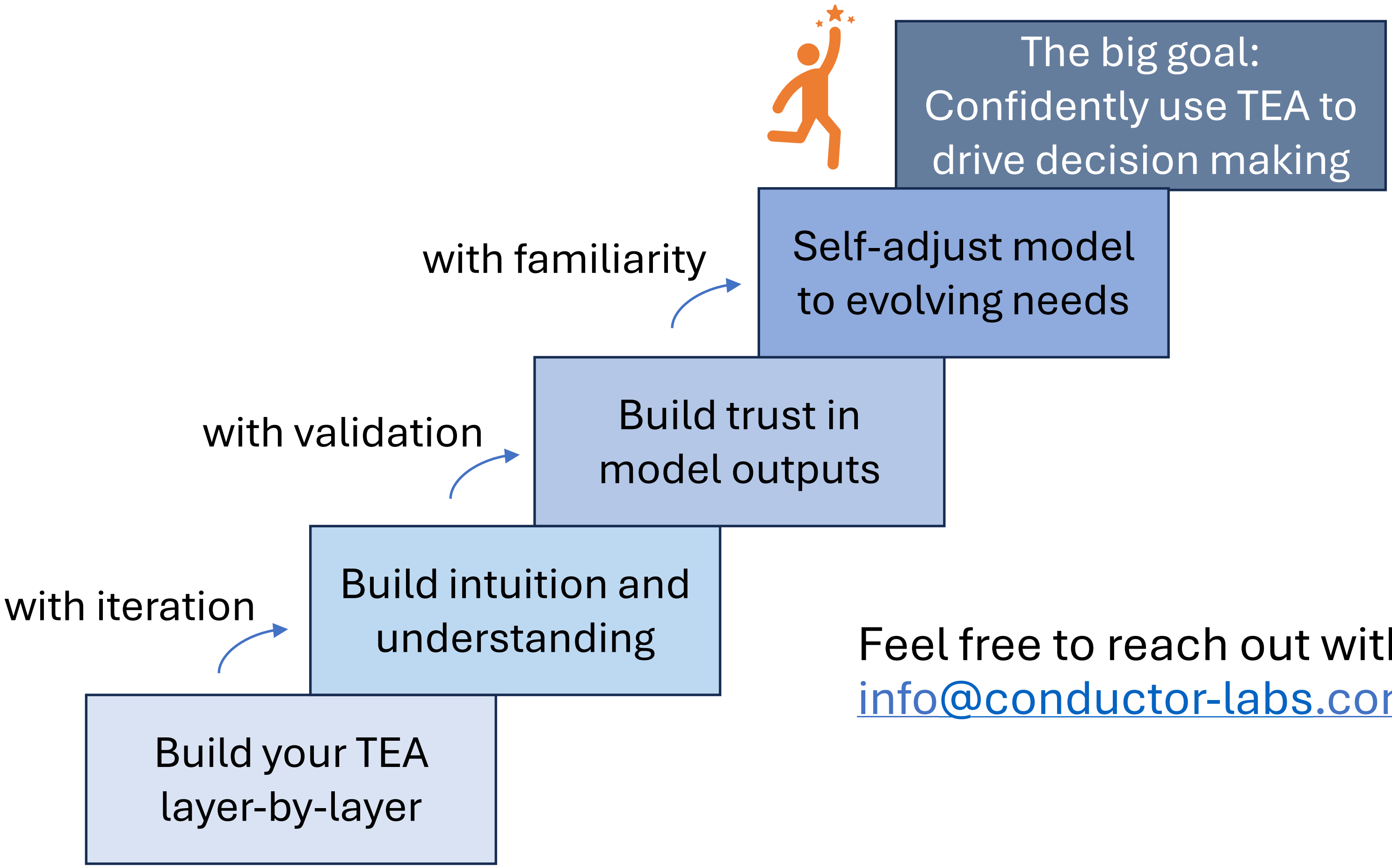
Data & assumptions:
- IEA Global Energy and Climate Model Key Input Data (https://www.iea.org/data-and-statistics/data-product/global-energy-and-climate-model-2023-key-input-data)
- NREL Assumptions Baseline (electricity & transportation) (https://atb.nrel.gov/) (https://atb.nrel.gov/electricity/2022/index)
- AssessCCUS (a lot of great curated resources) (https://assessccus.globalco2initiative.org/tea/databases/)
- Industry operating margins (https://pages.stern.nyu.edu/~adamodar/New_Home_Page/datafile/margin.html) (a lot of financial analysis benchmarks on Prof. Damodaran's website
- Capacity factors (key assumptions (e.g., solar isn't on all day)) (https://atb.nrel.gov/electricity/2022/technologies)

Calculators to gut check models:
- NREL LCOE calculator (https://www.nrel.gov/analysis/tech-lcoe.html)

Mental model building:
- ARPA-E TEA (https://arpa-e.energy.gov/sites/default/files/Stekli%20FOCUS%20Kickoff%20Presentation.pdf)

Next steps

My ask: Take ownership of your TEA!



Feel free to reach out with questions or follow-ups:
info@conductor-labs.com

Appendix

Building your intuition

Technoeconomic-Readiness-Level (TeRL)

TEA-RL	0-1	2-3	4-5	6-7	8-9
Technology scale	Conceptual idea	Lab scale	Pre-pilot scale	Pilot	Small demo
What it looks like	Excel: 1-2 sheets, simple process flow	Excel: 4-5 sheets, detailed process flow, sensitivities	Complex excel model for strategic planning AspenPlus for pilot design	AspenPlus: Detailed assumptions, real-world data, location specific	Industrial controls systems & planning feeding financial / operational models
Approximate effort	5 hr	50 hr	250 hr	1,000 hr	3,000 hr
Decisions to drive	Is there even a chance for this idea to be profitable?	What R&D decisions should I prioritize? Paths to choose between?	How should we optimize the tech stack the systems level for a pilot?	How do I optimize unit processes and metrics so that we can scale?	How do I avoid costly implementation mistakes with super high fidelity modeling?
Data inputs	Desktop searches, your expert judgement	Scale-up benchmarks, desktop research for big capex, technical expert(s)	Informed estimates for capex and opex via numerous vendor quotes and practitioner interviews	Detailed capex and opex (90% of costs as a line item)	Validated costs by independent 3rd party (98% of costs as a line item), negotiated contract data

Good place to start for most early stage teams

TeRL by Fellows from Breakthrough Energy
Concept inspired by ARPA-E Joe Stekli 2014

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Capex calculations

Calculating Annualized CAPEX*
1. Right-size each of the equipment (six-tenths rule)
2. Sum up all of the equipment and account for indirect costs
3. Annualize using capital recovery factor equation

1. Six-tenths rule: Modify a reference capex datapoint to the size needed for your system

$$C_B = C_A\left(\frac{S_B}{S_A}\right)^{0.6}$$

Where C_B = the approximate cost ($) of equipment having size S_B (cfm, Hp, ft^2, or whatever)
C_A = is the known cost ($) of equipment having corresponding size S_A (same units as S_B),
and S_B/S_A is the ratio known as the *size factor*, dimensionless.

https://www.pdhonline.com/courses/g127/g127content.pdf

3. Capital recovery factor: Simple way of estimating an annual capex cost, based on assumptions around plant life, cost of capital, and Total Capital Investment (see 2)

A **capital recovery factor** is the ratio of a constant annuity to the present value of receiving that annuity for a given length of time. Using an interest rate i, the capital recovery factor is:

$$CRF = \frac{i(1+i)^n}{(1+i)^n - 1}$$

where n is the number of annuities received.[1]

https://en.wikipedia.org/wiki/Capital_recovery_factor

2. Account for indirect costs: the purchase price of an equipment is only a small part of the total capex associated with that equipment. Here are some ranges & scalings to consider.

Table 6-17 Estimation of capital investment cost (showing individual components)

The percentages indicated in the following summary of the various costs constituting the capital investment are approximations applicable to ordinary chemical processing plants. It should be realized that the values given vary depending on many factors, such as plant location, type of process, and complexity of instrumentation.

I. **Direct costs** = material and labor involved in actual installation of complete facility (65–85% of fixed-capital investment)
- A. Equipment + installation + instrumentation + piping + electrical + insulation + painting (50–60% of fixed-capital investment)
  1. Purchased equipment (15–40% of fixed-capital investment)
  2. Installation, including insulation and painting (25–55% of purchased-equipment cost)
  3. Instrumentation and controls, installed (8–50% of purchased-equipment cost)
  4. Piping, installed (10–80% of purchased-equipment cost)
  5. Electrical, installed (10–40% of purchased-equipment cost)
- B. Buildings, process, and auxiliary (10–70% of purchased-equipment cost)
- C. Service facilities and yard improvements (40–100% of purchased-equipment cost)
- D. Land (1–2% of fixed-capital investment or 4–8% of purchased-equipment cost)

II. **Indirect costs** = expenses which are not directly involved with material and labor of actual installation of complete facility (15–35% of fixed-capital investment)
- A. Engineering and supervision (5–30% of direct costs)
- B. Legal expenses (1–3% of fixed-capital investment)
- C. Construction expense and contractor's fee (10–20% of fixed-capital investment)
- D. Contingency (5–15% of fixed-capital investment)

III. **Fixed-capital investment** = direct costs + indirect costs

IV. **Working capital** (10–20% of total capital investment)

V. **Total capital investment** = fixed-capital investment + working capital

https://books.google.ca/books/about/Plant_Design_and_Economics_for_Chemical.html?id=3uVFkBBHyP8C&redir_esc=y