ENGINEERING FOR impact

mit 6.900

Lecture 1

February 6, 2024

Make something real.

TODAY

- What is this class about?
- What will I learn?
- Some logistics
- Let’s get started – HW/SW product design

6.900 staff

Instructors

Joel Voldman

Joe Steinmeyer

TAs

Zoe Wong

Raiphy Jerez

Special guests

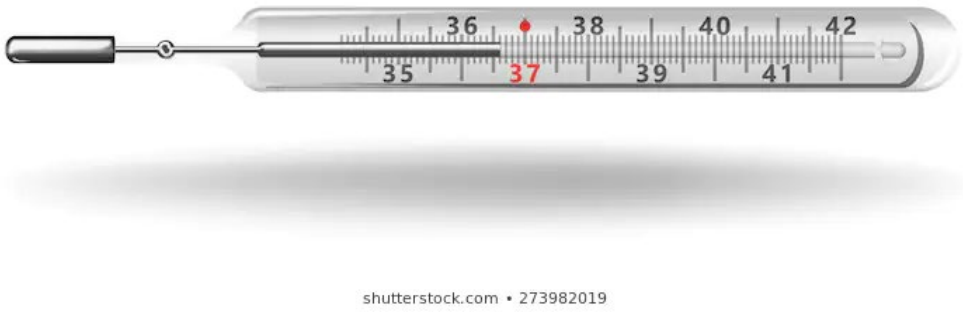
Sanjana Paul
Carlos Cruz-Casas
Tony Hu
BOSE engineers
And more…

Consider the medical thermometer

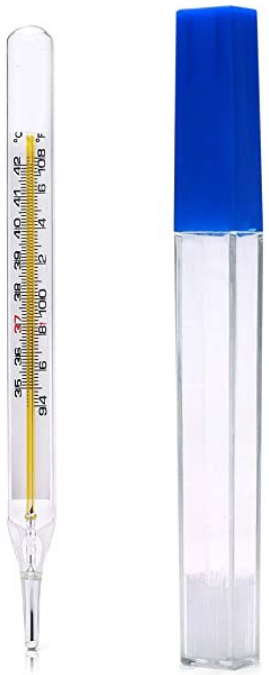
Why do we use medical thermometers?

What features do we want?

mercury thermometer



alcohol thermometer



Consider the medical thermometer

ear thermometer

Range: 34-42.2 °C
Accuracy: ±0.2 °C
Time: ~3 sec
Price: $55

oral thermometer

Range: 32-42.9 °C
Accuracy: ±0.1 °C
Time: ~10 sec
Price: $7

Today's thermometers

Consider the medical thermometer

ear thermometer

Range: 34-42.2 °C
Accuracy: ±0.2 °C
Time: ~3 sec
Price: $55

oral thermometer

Sensing, electronics, computation, actuation (display)
[some even have Bluetooth communications]

Consider the drill/driver

Why do we use drill/drivers?

What features do we want?

handheld screwdriver

handheld drill

Consider the drill/driver

time →

manual

corded drill/driver
~1900s

cordless drill/driver
1978

cordless drill/driver with brushless motor, tool tracking, etc.
today

circuits, actuation

sensing, electronics, computation, comms, actuation

Consider the drill/driver

Isolated cases?

These are all hardware/software systems

Our definition: A system that has most of:

- Sensing
- Electronics
- Computation
- Software
- Communications
- Control
- Actuation

Though not a formal law, products ➔ HW/SW over time

To develop these systems

We need expertise in

- Sensing
- Electronics
- Computation
- Software
- Communications
- Control
- Actuation

} **our focus**

And yes,

- Industrial design, mechanical, thermal, manufacturing, medical, economics, marketing, etc.

To develop these systems

In industry, you'll probably be on a team that does ~1 of these functions

But you'll be a better engineer if you can understand the rest to some extent

In this class, we'll undertake this *full stack* design

So we'll need to synthesize material *across* classes

Our *responsibility* as engineers

ars TECHNICA

BIZ & IT TECH SCIENCE POLICY CARS GAMING & CULTURE

HIGH AND DRY —

SmartDry's useful laundry sensor to be cloud-bricked next month

Sensor for already dry clothes relied on smartphone app, servers to wor

KEVIN PURDY - 8/30/2022, 1:14 PM

WIRED

BACKCHANNEL BUSINESS CULTURE GEAR IDEAS POLITICS SCIENCE SECURITY MERCH

SIGN IN | SUBSCRIBE

KLINT FINLEY BUSINESS APR 5, 2016 6:06 PM

Nest's Hub Shutdown Proves You're Crazy to Buy Into the Internet of Things

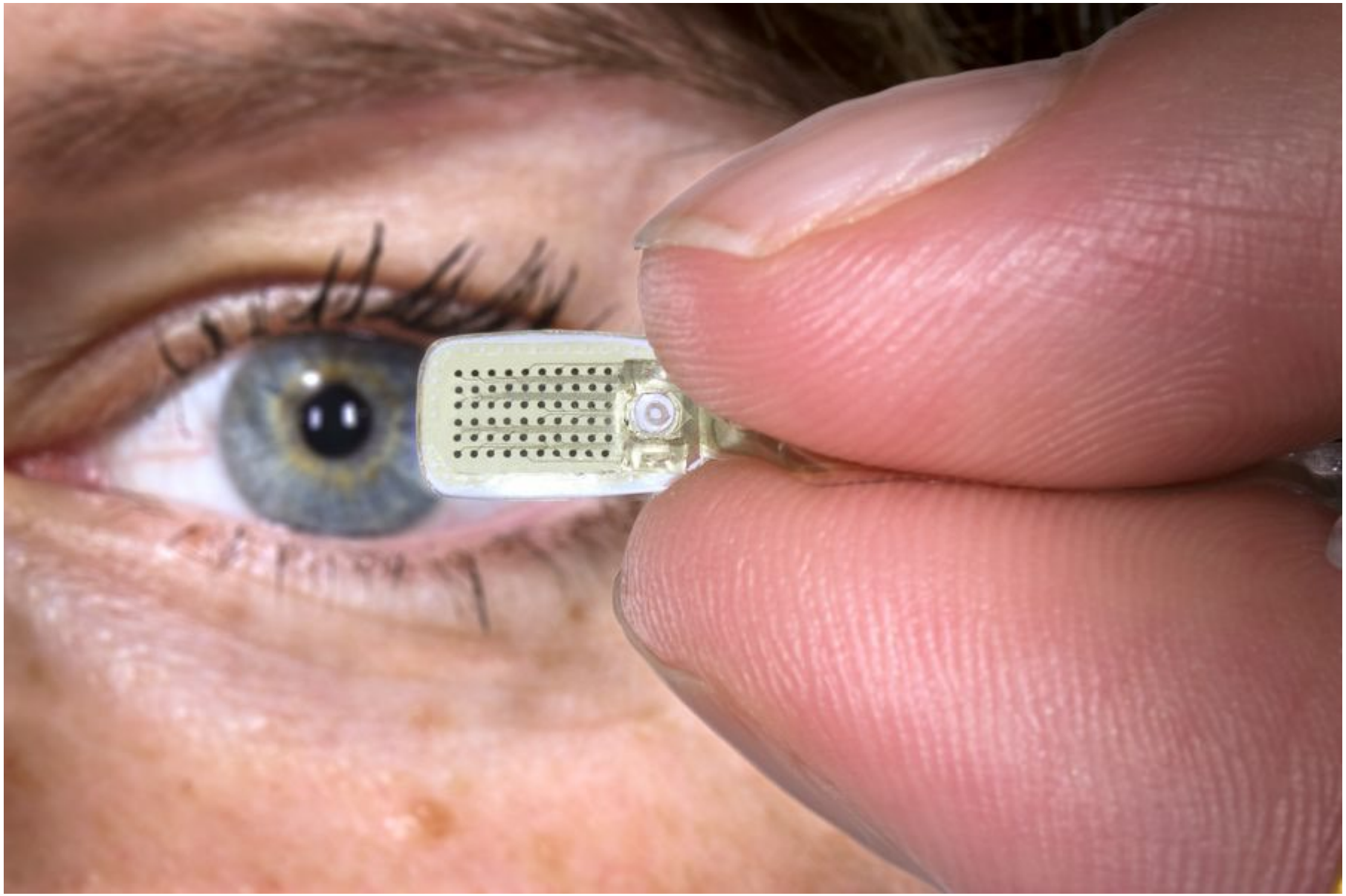
Nest's decision sends a pretty clear signal that you just can't rely on "Internet of Things" things.

REVOLV

Our *responsibility* as engineers

Markus Möllmann-Bohle has been left to manage his implanted electronic device alone. Credit: Nyani Quarmyne/Panos Pictures for *Nature*

Our *responsibility* as engineers



Our *responsibility* as engineers

Our *responsibility* as engineers

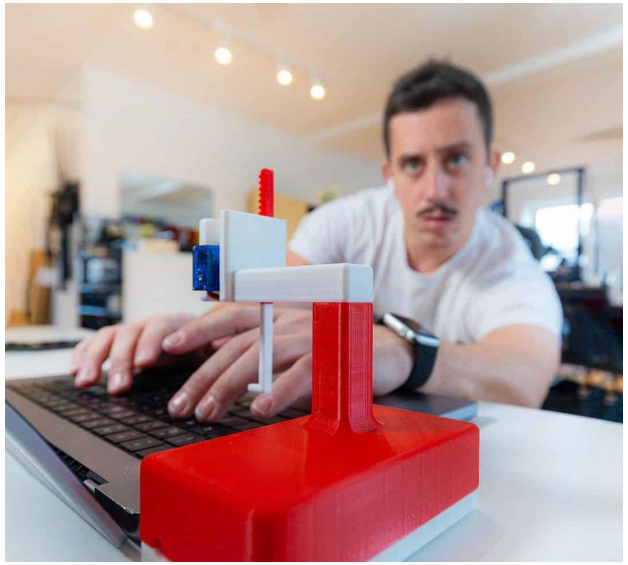
Our *responsibility* as engineers

as engineers who can harness extremely powerful technologies,

we must be mindful of the *implications* of the choices we make in those designs

Let’s talk about *impact*

- There are many reasons to create new HW/SW systems
- Arguably, every HW/SW system has impact…



tHe tEeN TyPEr™, Matt Benedetto [Unnecessary Inventions]

Our reason: to improve the world around us…to use our skills to help those who can’t do what we can do

Let's talk about *impact*

- There are many reasons to create new HW/SW systems
- Arguably, every HW/SW system has impact…

BigBelly's Solar trash compactor and recycling cans

Juicero

More here… than here

Our reason: to improve the world around us…to use our skills to help those who can't do what we can do

Our project this term

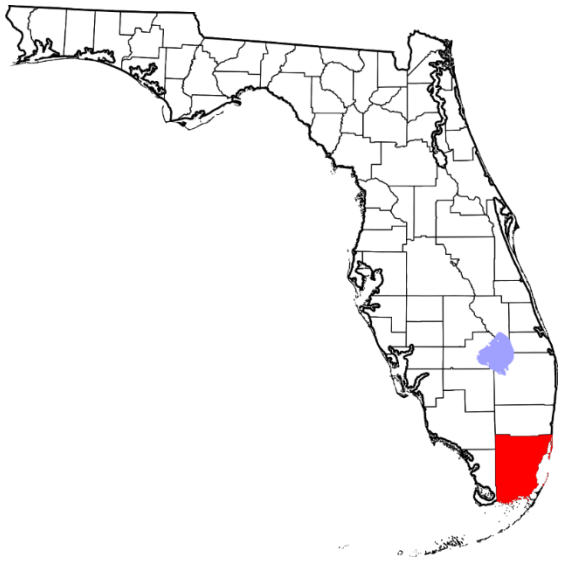
- We'll spend Thursday's lecture on this, but…
- We're partnering with two organizations via MIT's PKG Center
- One project with two "customers", closely related requirements

PKG

PRISCILLA KING GRAY
PUBLIC SERVICE CENTER

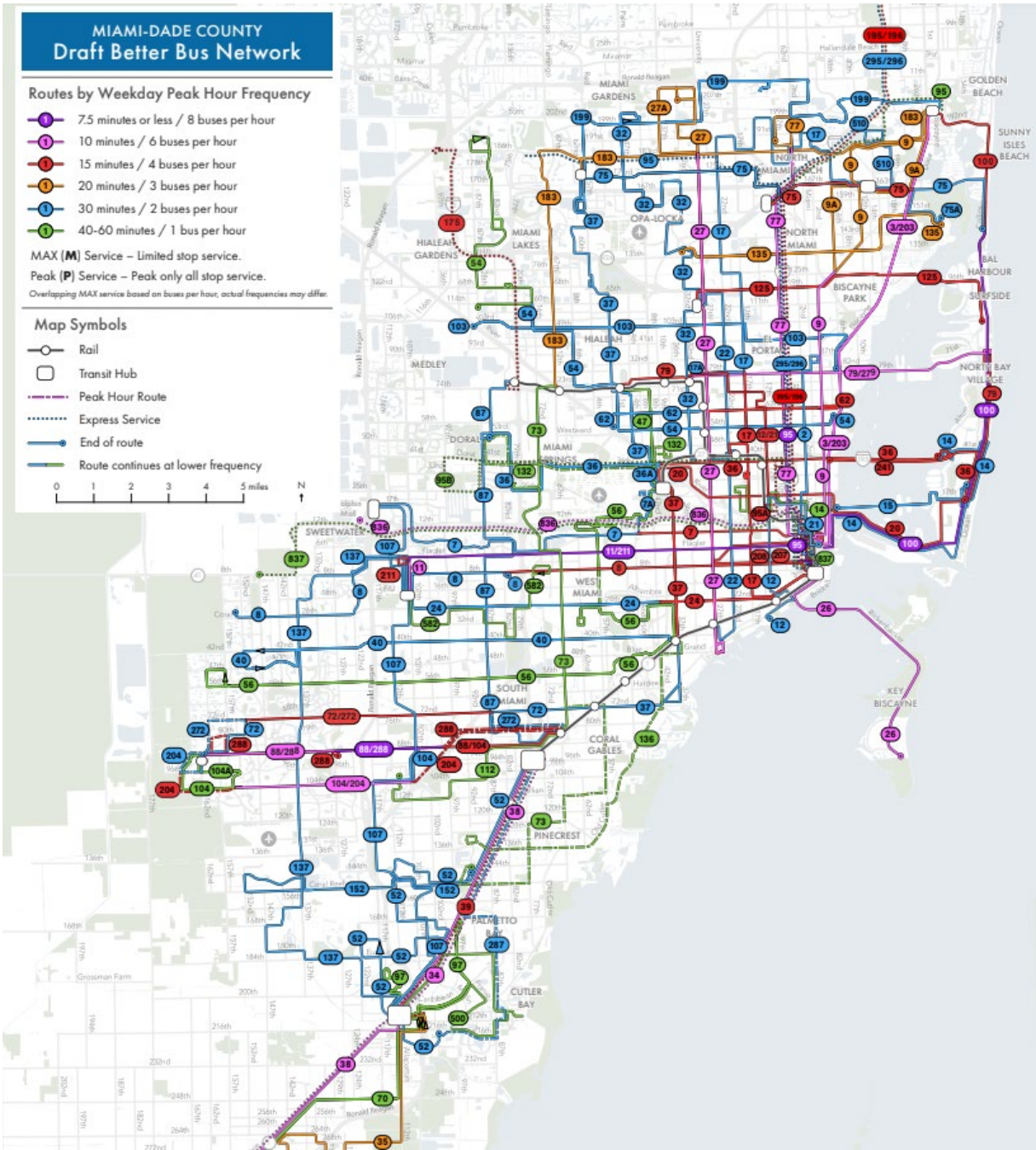
MIT Office of Sustainability

MIAMI-DADE COUNTY



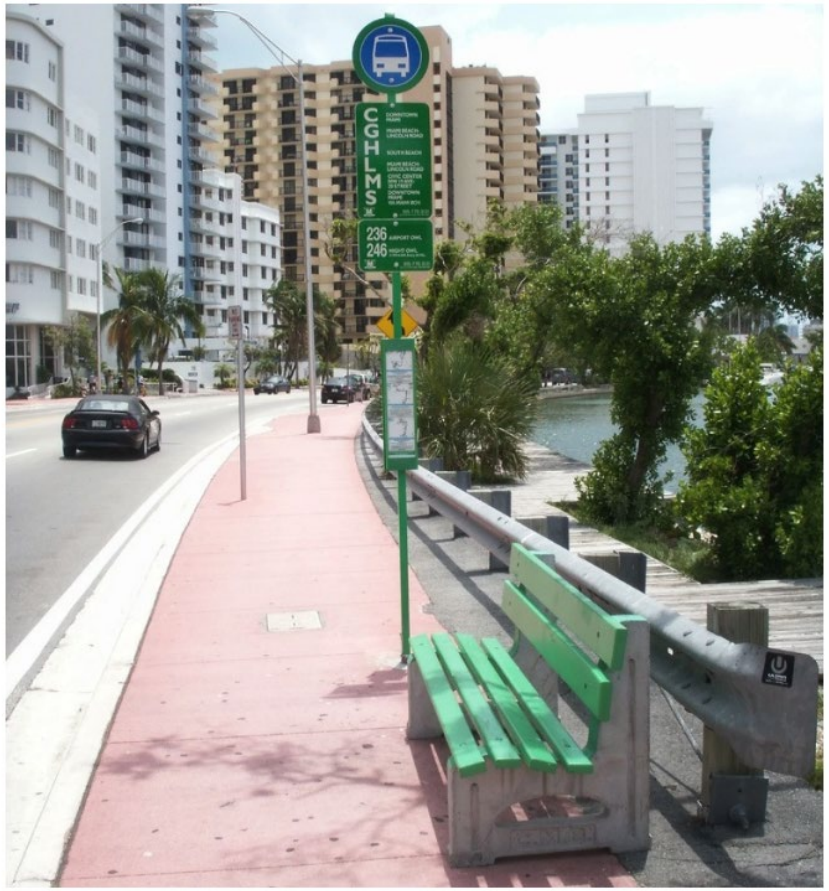
Our project this term

- Miami-Dade County has an extensive bus transit network (>7k stops)
- They want to increase use of public transit ➔ serve community, reduce emissions
- But riders will only use system if it is convenient and comfortable
- They know who is taking the bus, where they get on and get off, where their buses are, etc.



Our project this term

- But they don’t know who **isn’t** taking the bus
- Who comes to the bus stop but leaves because it is too hot



An uncovered bus stop on South Beach

Credit Vera Arias /

Bus stops like this one can get very hot in the summer.

https://www.wlrn.org/news/2014-06-19/we-asked-miami-dade-transit-why-not-every-bus-stop-has-a-shelter

Our project this term

- They want to deploy resources to make the bus stops more comfortable…here is the current metric

> Albert Hernandez is assistant director for the Division of Engineering, Planning and Development at Miami-Dade Transit.
>
> He says the lack of shelters is apparently not due to money.
>
> **Walk me though what the process is for getting a bus shelter in Miami-Dade County.** Bus shelters are placed at bus stops with the greatest amount of patrons. ... We require at least 100 boardings per day at the location. ... We place bus benches at all locations that do not have shelters.

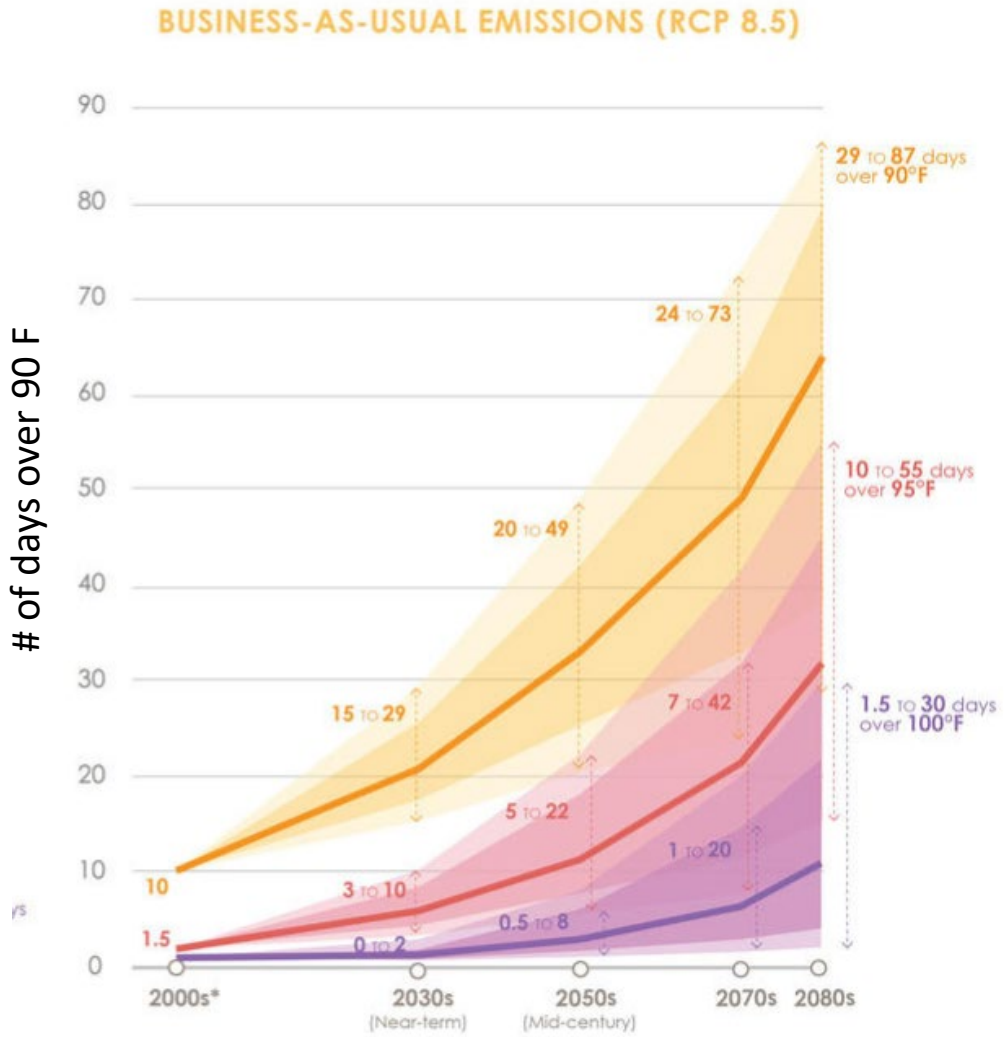
- What's incomplete about this metric?

https://www.wlrn.org/news/2014-06-19/we-asked-miami-dade-transit-why-not-every-bus-stop-has-a-shelter

Our project this term

Office of Sustainability

- MITOS is working with SA+P and now us to understand heat islands at MIT
- Boston is getting hotter →



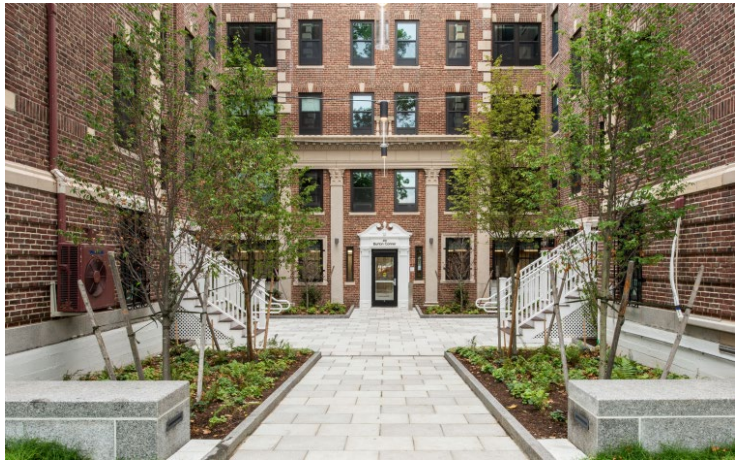
https://www.boston.gov/environment-and-energy/heat-resilience-solutions-boston

Our project this term

Office of Sustainability

- MITOS is working with SA+P and now us to understand heat islands at MIT
- Boston is getting hotter ⟶
- What about MIT?

- Can we measure hyperlocal heat and see how it affects space usage?



Our project this term

Office of Sustainability

- MITOS is working with SA+P and now us to understand heat islands at MIT
- Boston is getting hotter
- What about MIT?

- Can we measure hyperlocal heat and see how it affects space usage?
- Temperature is not as simple as it sounds…

https://www.youtube.com/watch?v=hTVlegPt0-g

Our project this term

- In both cases, our partners want to measure hyperlocal heat experience **and** occupancy (how many people are around, and for how long)

Our project this term

If we're successful, we can help MIT & Miami-Dade understand where to plant new trees, add fans or awnings or bus shelters, etc.

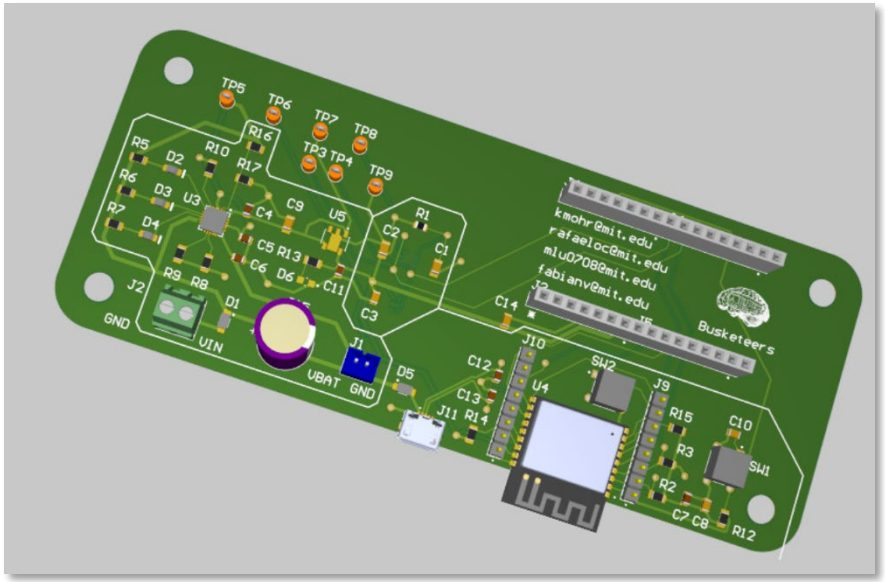
so that the community can be better served

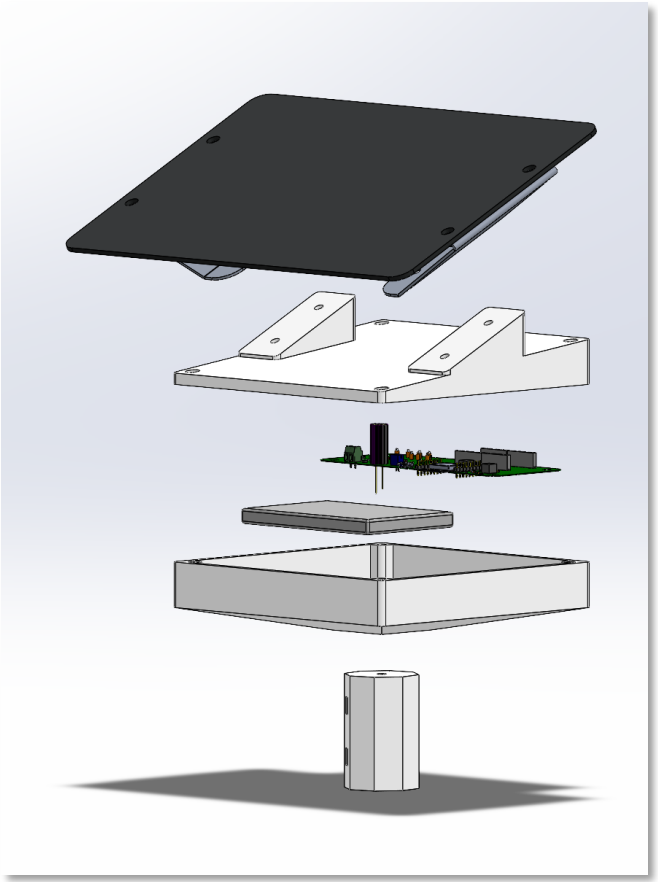
and there is lots of interest in these types of systems

from other communities

A bit of a head start

- We worked with Miami-Dade last year, so teams this year can utilize those learnings





A bit of a head start

- And Sanjana Paul developed a first-gen system for MITOS, which she'll describe on Thu

What will I learn?

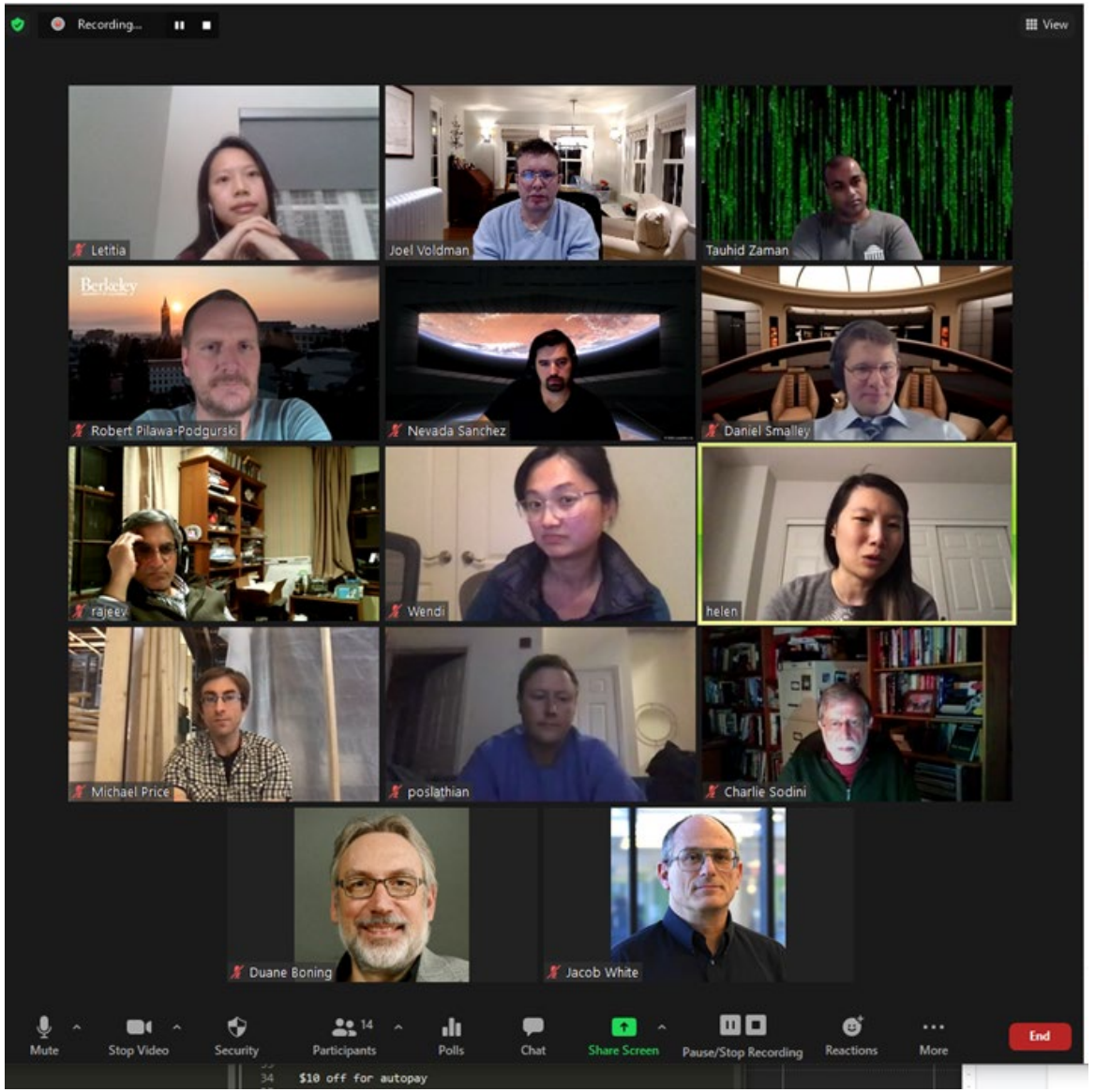
- Principled ways to design HW/SW systems
- How to go from requirements ➔ specifications ➔ system design ➔ detailed design ➔ prototyping ➔ testing & verification
- How different system design choices and partitions affect tradeoffs in meeting our specifications
- Evaluate the size, weight, power, performance, cost, lifetime, etc. tradeoffs of various designs

Mostly, how to **synthesize and apply** your knowledge from other EECS classes

And yes, you'll build stuff

How will we do it?

- We'll work in teams…**BIG*** teams
- Why?
  - IRL, this is the way
  - Feedback from alumni
  - You can do more…together



*for EECS

How will we do it?

- You'll work in teams to set specifications
- You'll adapt & refine system diagrams based on those specs
- And develop testing & verification plans to meet those specifications
- Then go and implement

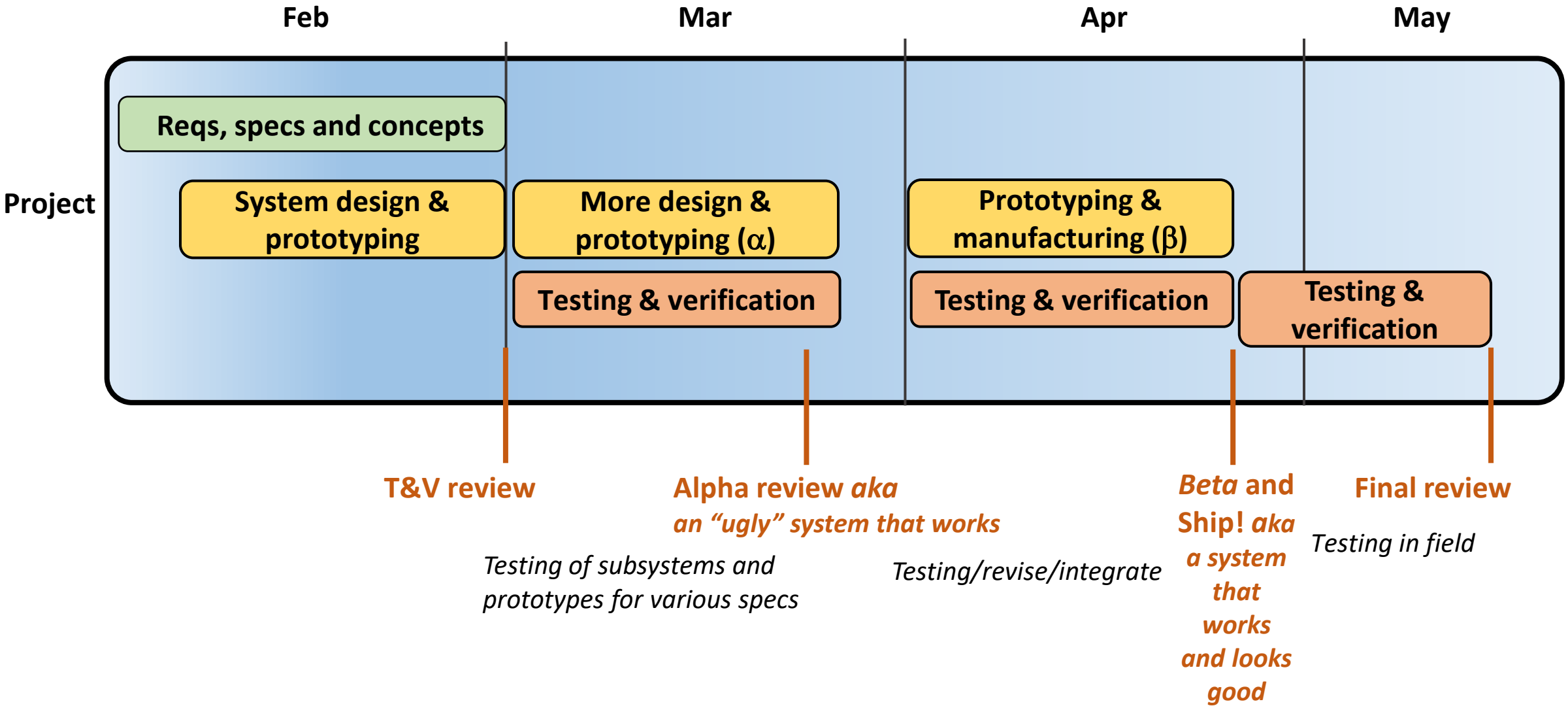
Multiple rounds of prototyping & testing

Along the way, there will be plenty of feedback from staff, partners, teammates, other teams…including mentoring sessions with BOSE engineers

How will we do it?

- We'll be joined by experts in HW/SW product development to provide insight and guidance
- Industrial Design (Tony Hu, MIT)
- Product development (Mark Bergeron, BOSE)
- Testing and verification (Rich Pyatt, BOSE)
- Packaging & environmental resistance (Sohan Abraham, BOSE)
- EMI/Certifications (John Yee, BOSE)

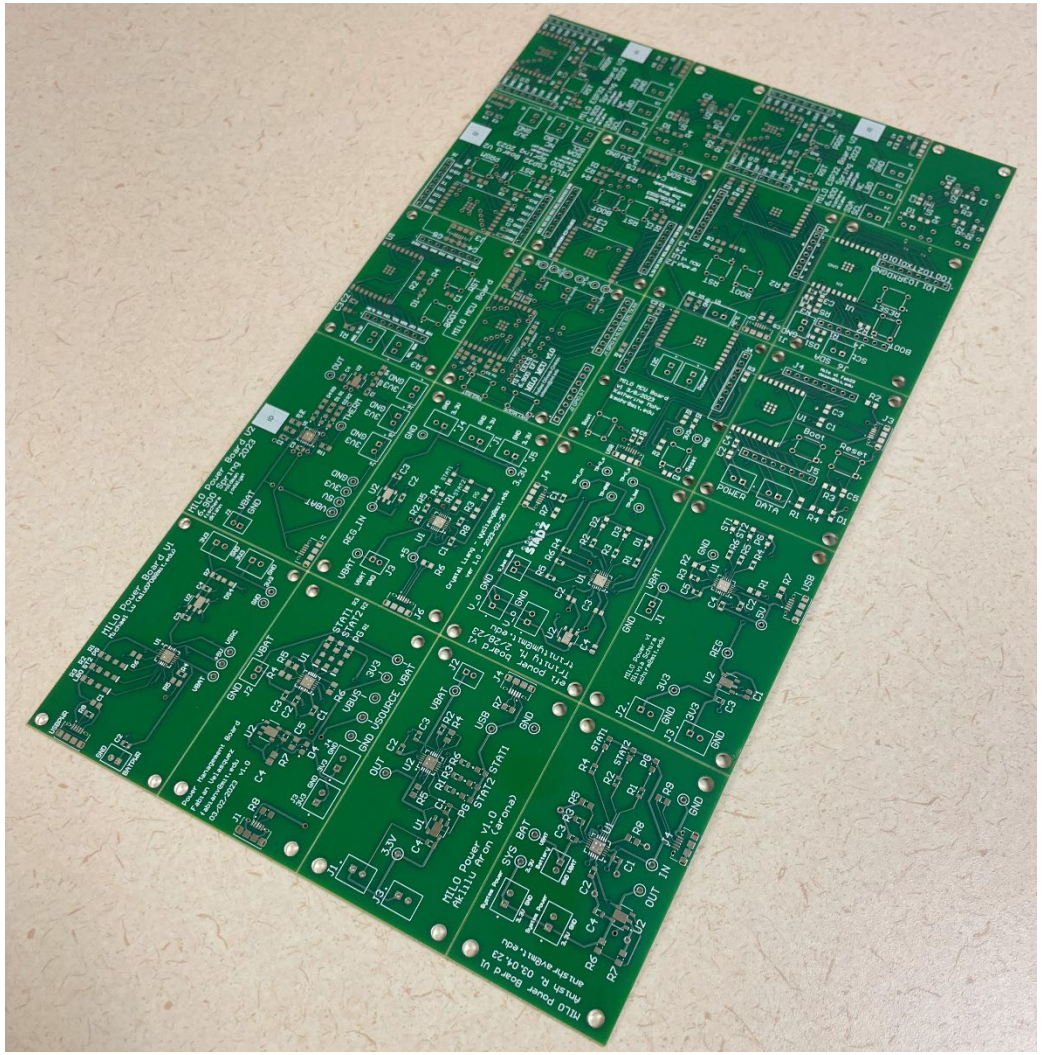
How will we do it?

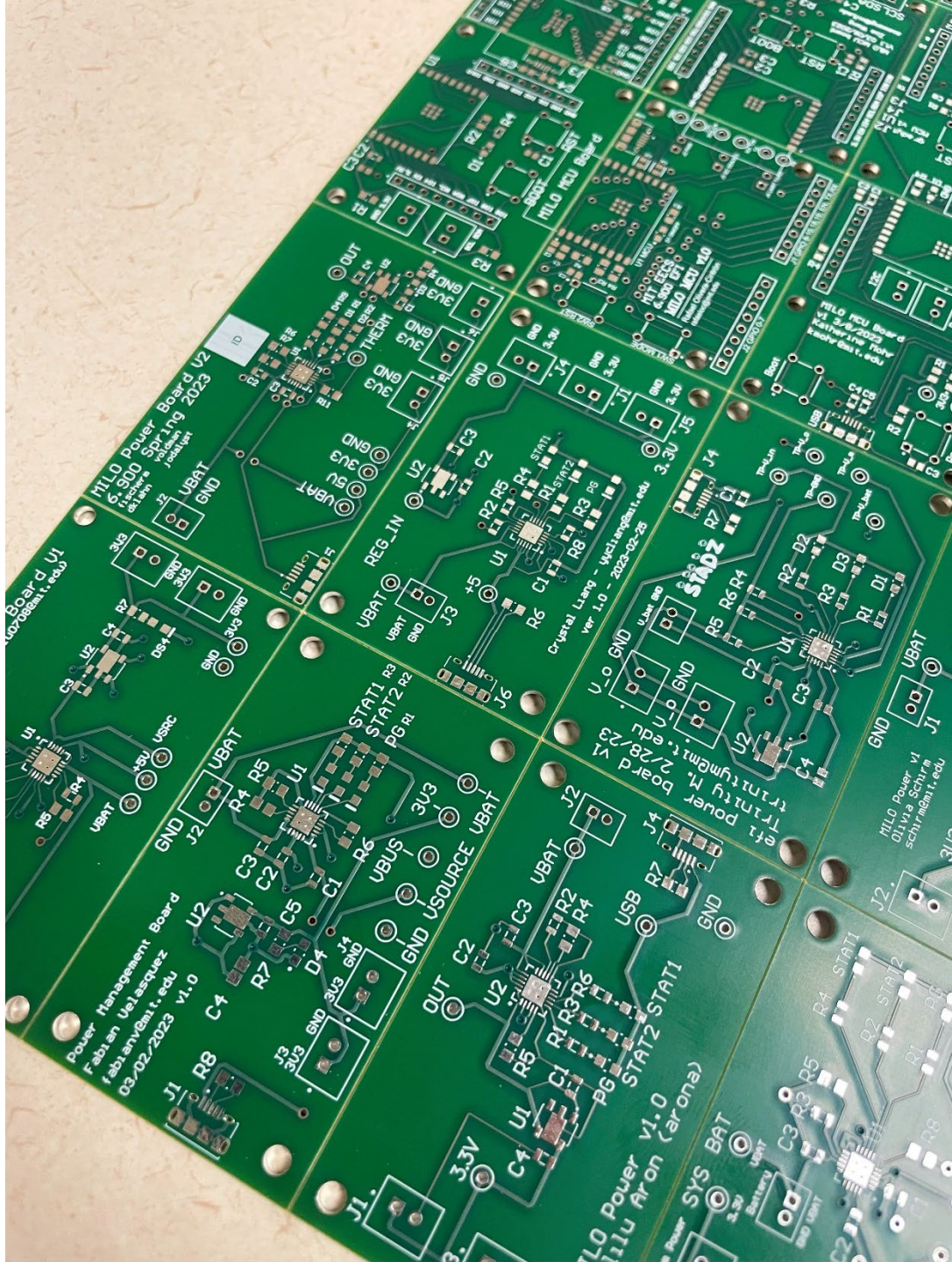


How will we do it?

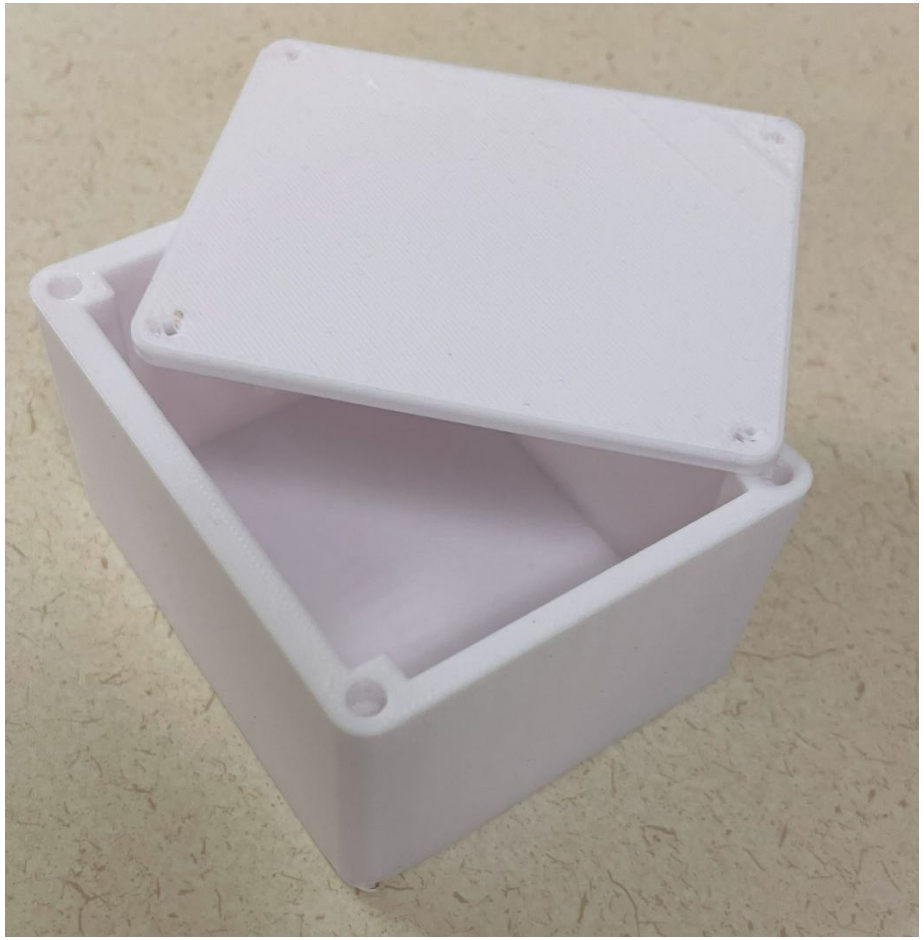
- During the first half of the term, we'll design and prototype **MAQS**
  - **M**it **A**ir **Q**uality **S**ystem
- A "development system" that incorporates sensing, compute, communications, server, db, in a guided experience
- Mostly individual, some parts as a team
- Every student gets to learn electronics design, PCB schematic design & layout & assembly, firmware, 3DP enclosures, back-end server w/ database & web server
- This will give you some of the tools needed to undertake the project

How will we do it?





How will we do it?



Full disclosure

- This is our second offering of this class
- There are no real templates anywhere for how to do this

We're not going to get it perfect!

Full disclosure

- This is our second offering of this class
- There are no real templates anywhere for how to do this

We're not going to get it perfect!

But…

- You get to help shape the class, not just the system
- You are the pioneers, the trailblazers, the early adopters
- We will be somewhat lenient in grading
- You will learn how to be real engineers
- You will gain confidence in your skills
- You will have an experience & a system to talk about with employers
- ~~You~~we will have fun

Do I have the background?

- In steady state, this class will require 6.200[6.002], 6.191[6.004], 6.310[6.302]
- For this second offering, we are going to be a bit lax

If you're worried about your background, come talk with us…

Some logistics

- This afternoon: team formation survey in EX00 – **due end of Saturday!!**
- Teams will go out on Sun or Mon, teams based on background **& interests**

- Labs are on Wednesday 1-4p – starting tomorrow!
  - Go to our catsoop website to install necessary software *before* lab tmrw
  - By the end of Lab01, you will have a battery-powered cloud-connected portable weather monitor
  - By the end of EX01, you will have made a complete end-to-end IoT system…pretty cool
- Psets every week or so – EX01 comes out today
- No exams
- Piazza ← sign up!
- There will be presentations, but this is not a CI-M class…
- Late policy, etc. on catsoop site

efi.mit.edu

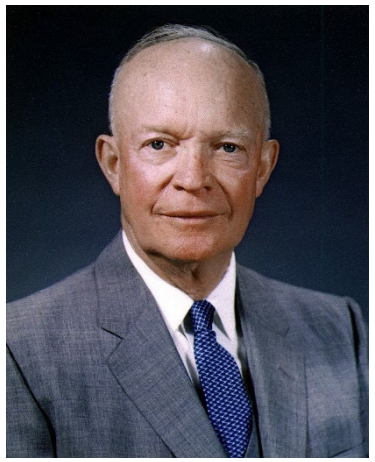
Let’s get started

HW/SW product development

- *with a focus on engineering design*
- Using MAQS as an example

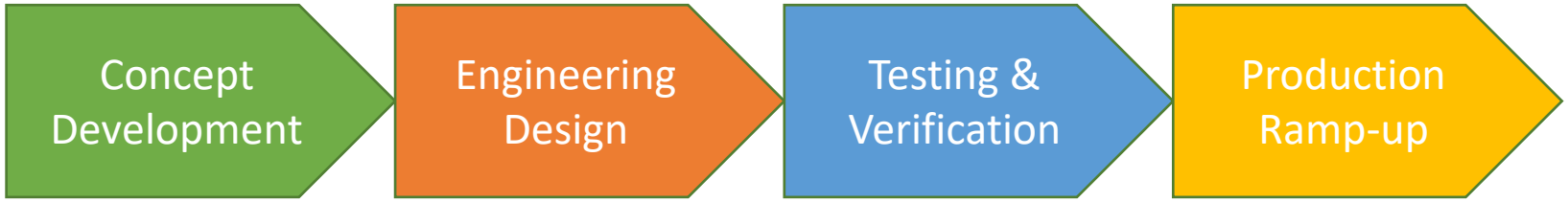
“In preparing for battle I have always found that plans are useless, but planning is indispensable”

--Dwight D. Eisenhower



Product development process

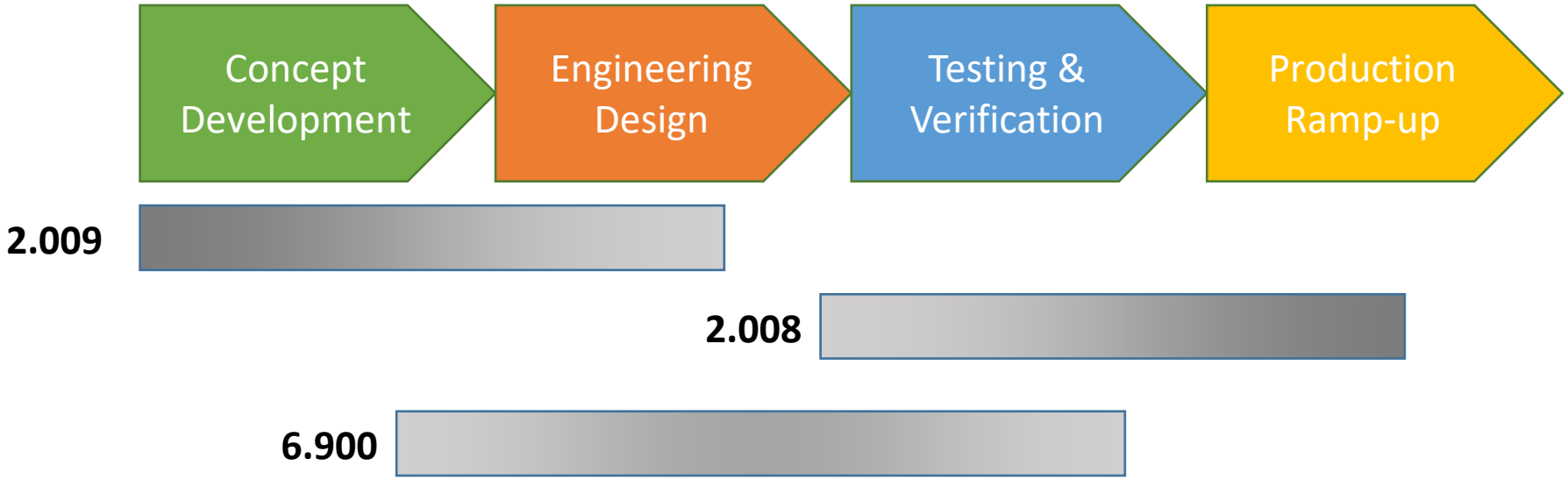
- Many different specific processes, terminology, number of steps, and so on, but generally



- Concept development: identify requirements, establish target specifications, generate concepts, refine and select most promising concept
- Engineering design: develop product's system-level architecture, partition into subsystems, design subsystems, prototype subsystems, integrate back into system
- Testing & verification: Evaluate the subsystems and complete system, verifying that it meets spec
- Production ramp-up: Transfer to manufacturing, verify quality, ramp up production, commercialization

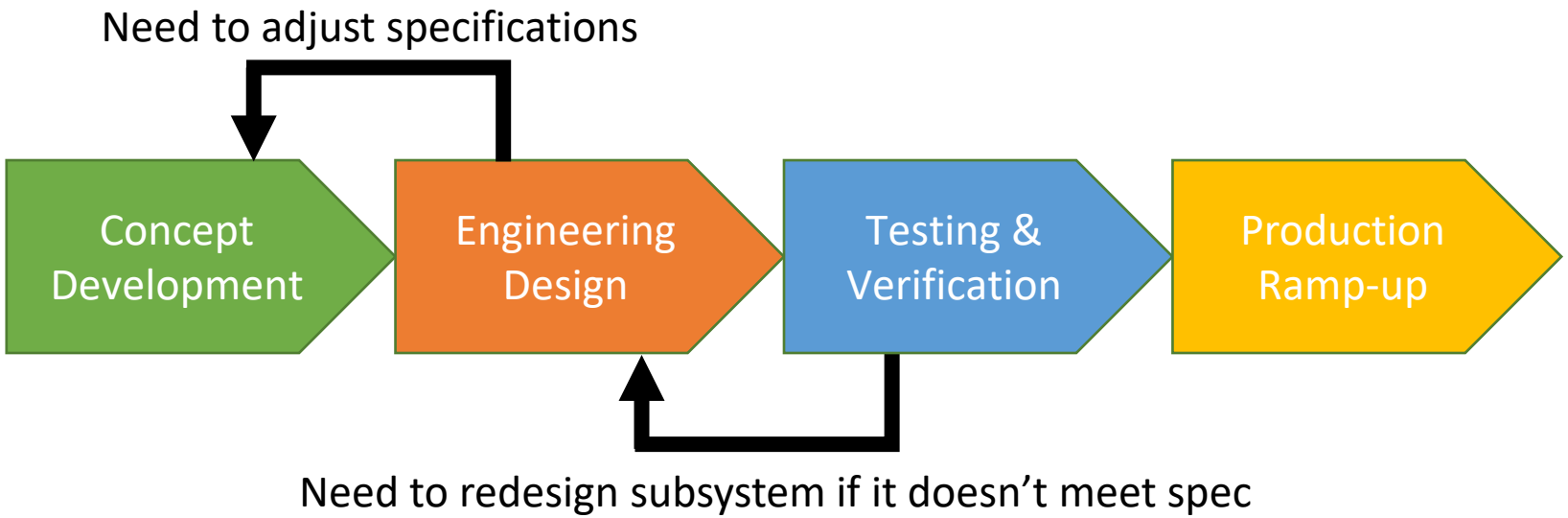
Product development process

- There are classes at MIT that focus on different aspects of this process
- It's too much for a single class!



Product development process

- This process is not linear…**iteration will be necessary**



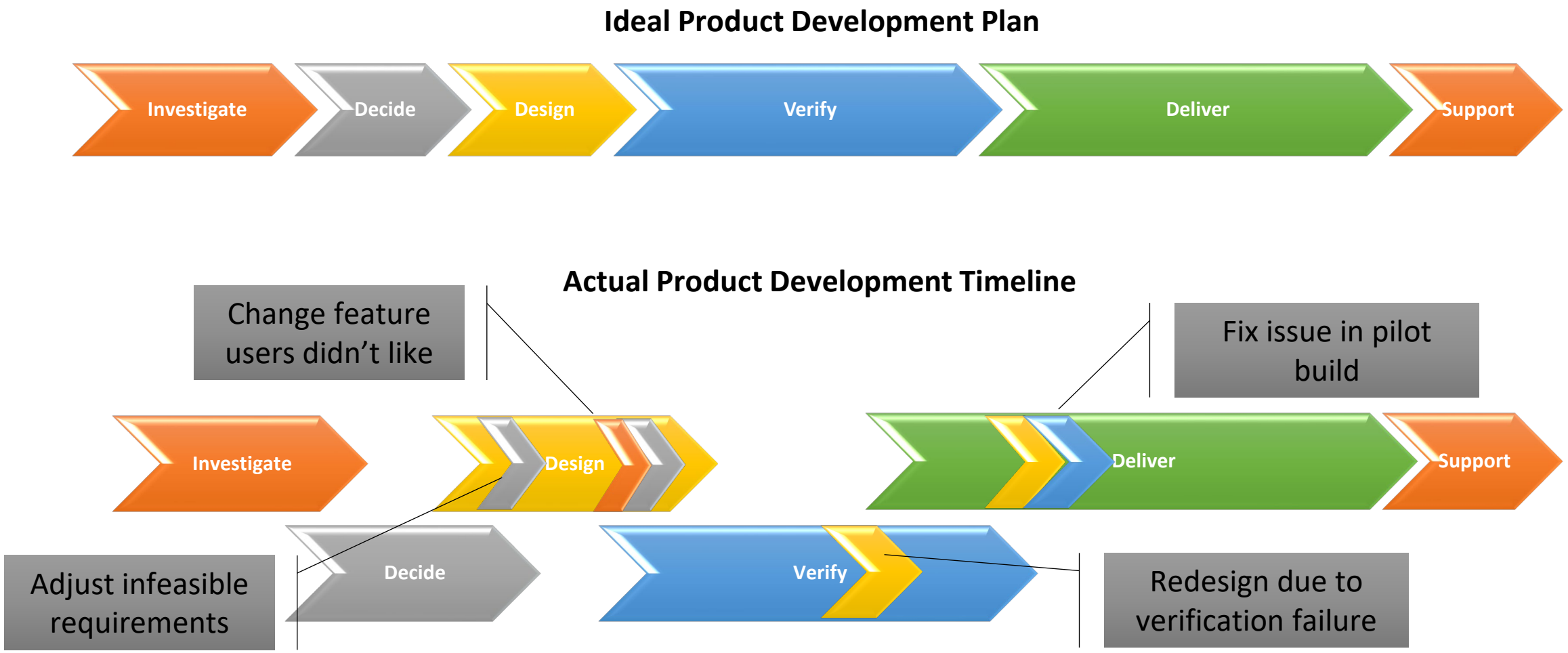
- But the farther you go to the right, retrenching gets more $$$
- So the more you can figure out early on…the better

Product development process

- Each step takes different amounts of time, depending on product, market, etc.

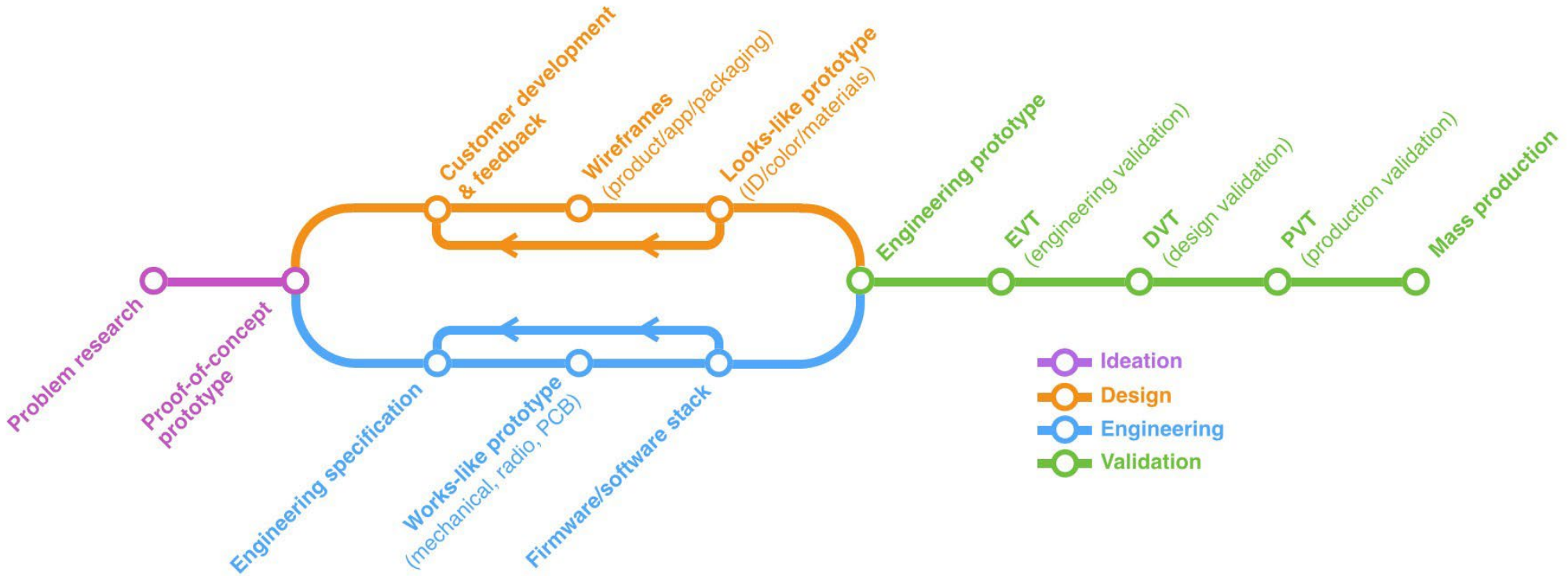
Product development process

- Here is Milwaukee Tool's product development process



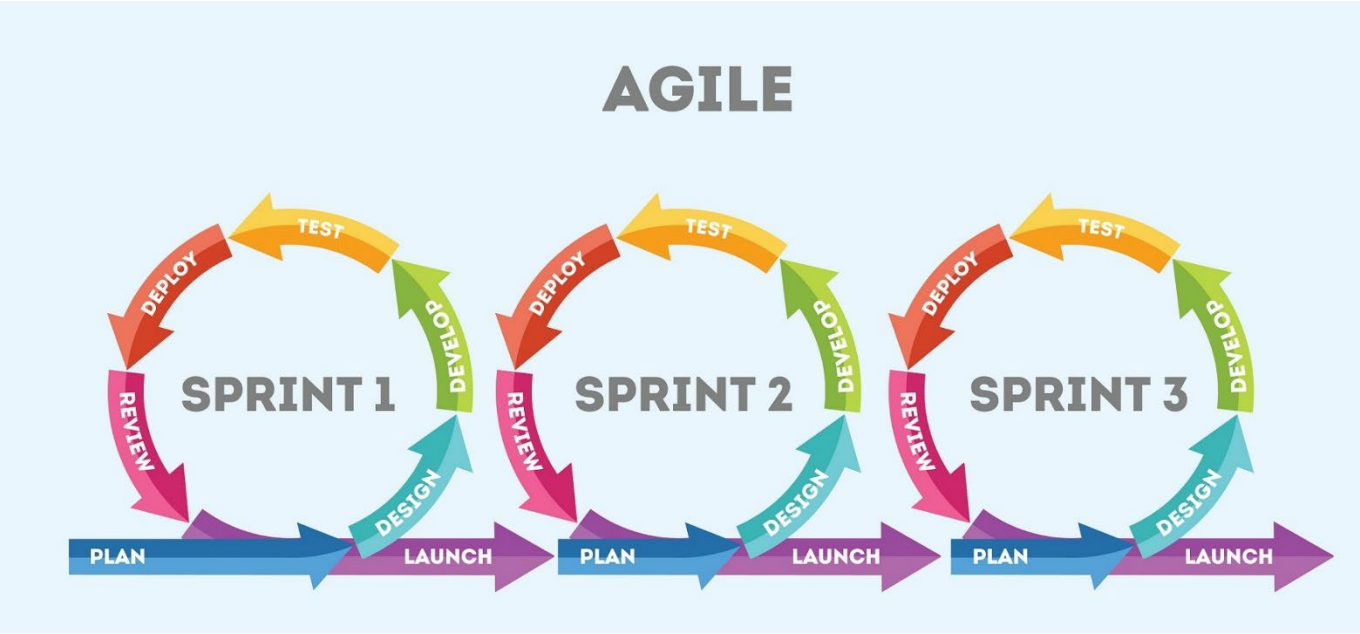
Product development process

- Here is Bolt.io's HW/SW product development process

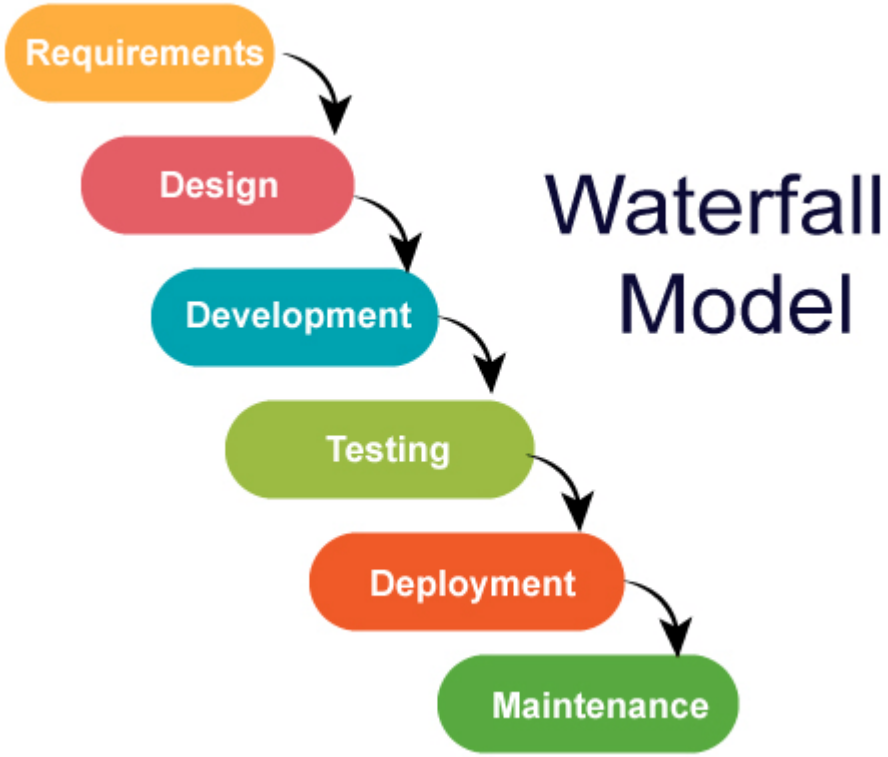


Product development process

- You may also hear about “waterfall” and “agile”



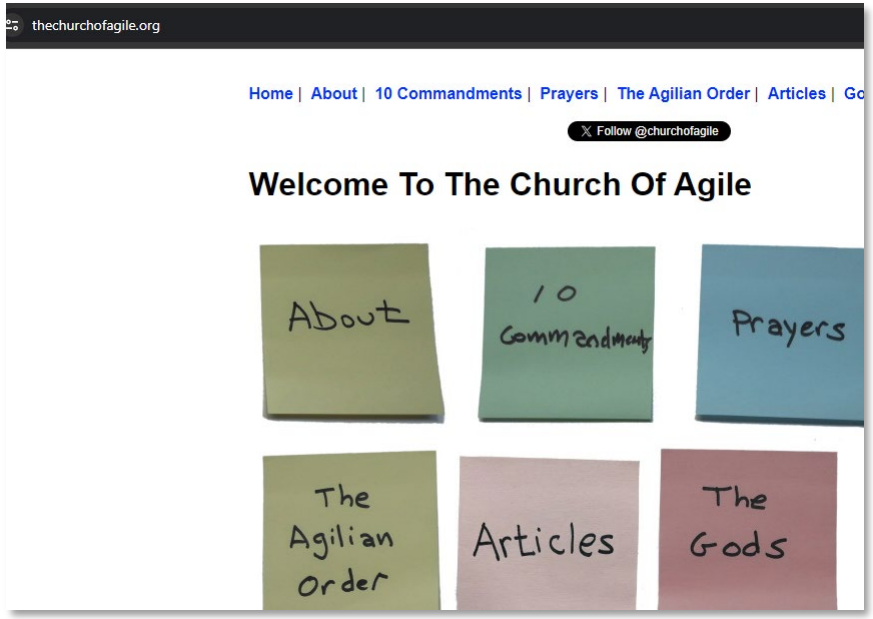
https://www.soldevelo.com/



https://medium.com/@chathmini96/waterfall-vs-agile-methodology-28001a9ca487

Product development process

This stuff gets quasi-religious…



Product development process

This stuff gets quasi-religious…

…in practice it's often a mix

Product development process

The two most important points for us:

1. **Have a plan**
2. **Write stuff down**

HW/SW product development

What's special about HW/SW products?

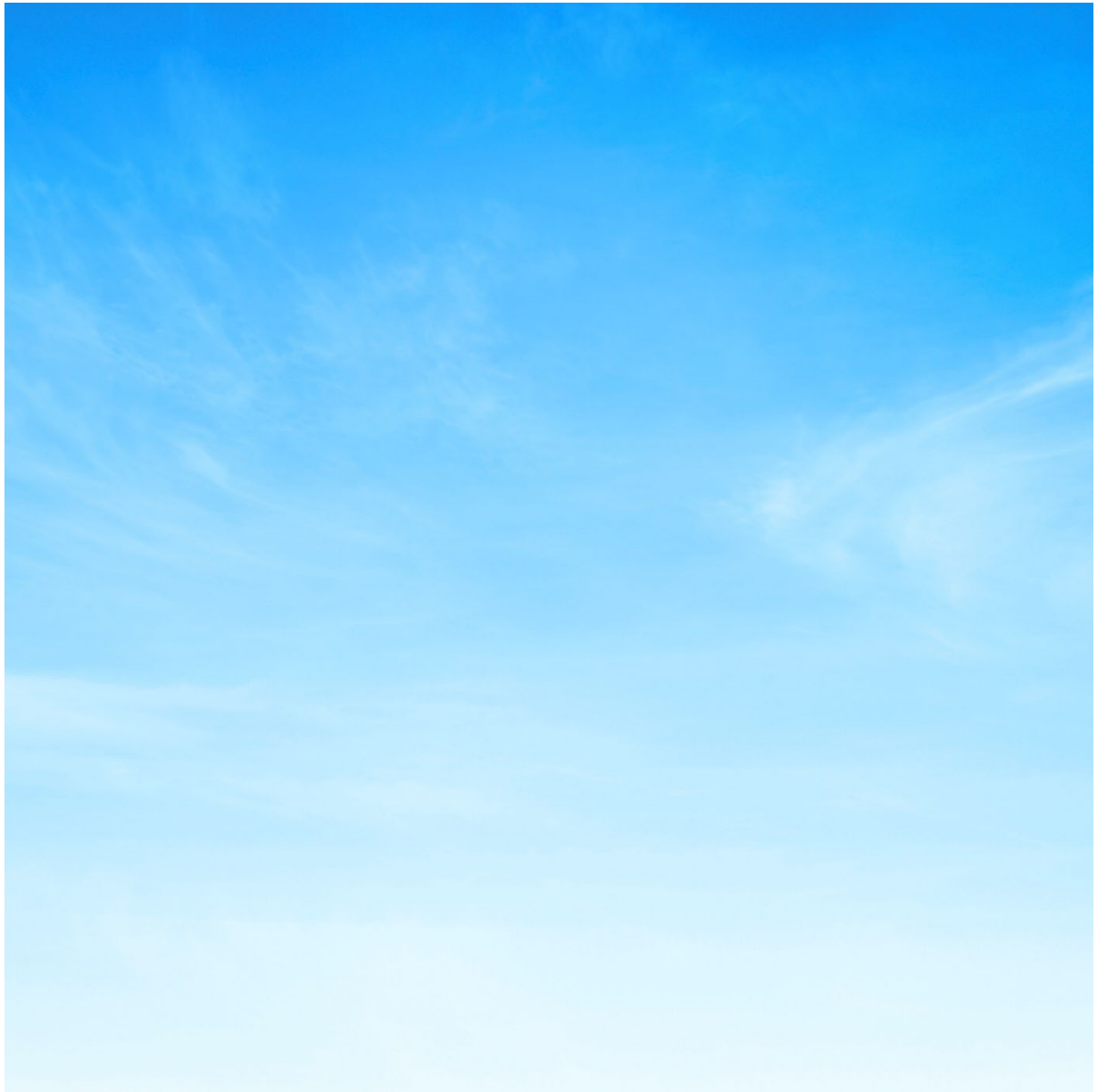
- They have commonly recurring sets of specifications
- Prototyping nowadays is easier, faster, and cheaper than in some other sectors
  - And in the past
- You can often change the SW after the product goes out…kinda hard to change the HW!
  - This makes part of the product static (HW) and part dynamic (SW) → we can use that!
  - In fact, the ability to update the firmware is often an important requirement ➔ implies some sort of connectivity, typically wireless
    - A great example of SW requirement impacting HW (need radio transceiver on-board)

MAQS: the MIT Air Quality Monitor

- Air ideally is
  - 78% N_2
  - 21% O_2
  - 0.9% Ar
  - 0.03% CO_2
  - Water vapor
  - Trace gases

Anything else is undesirable… such as

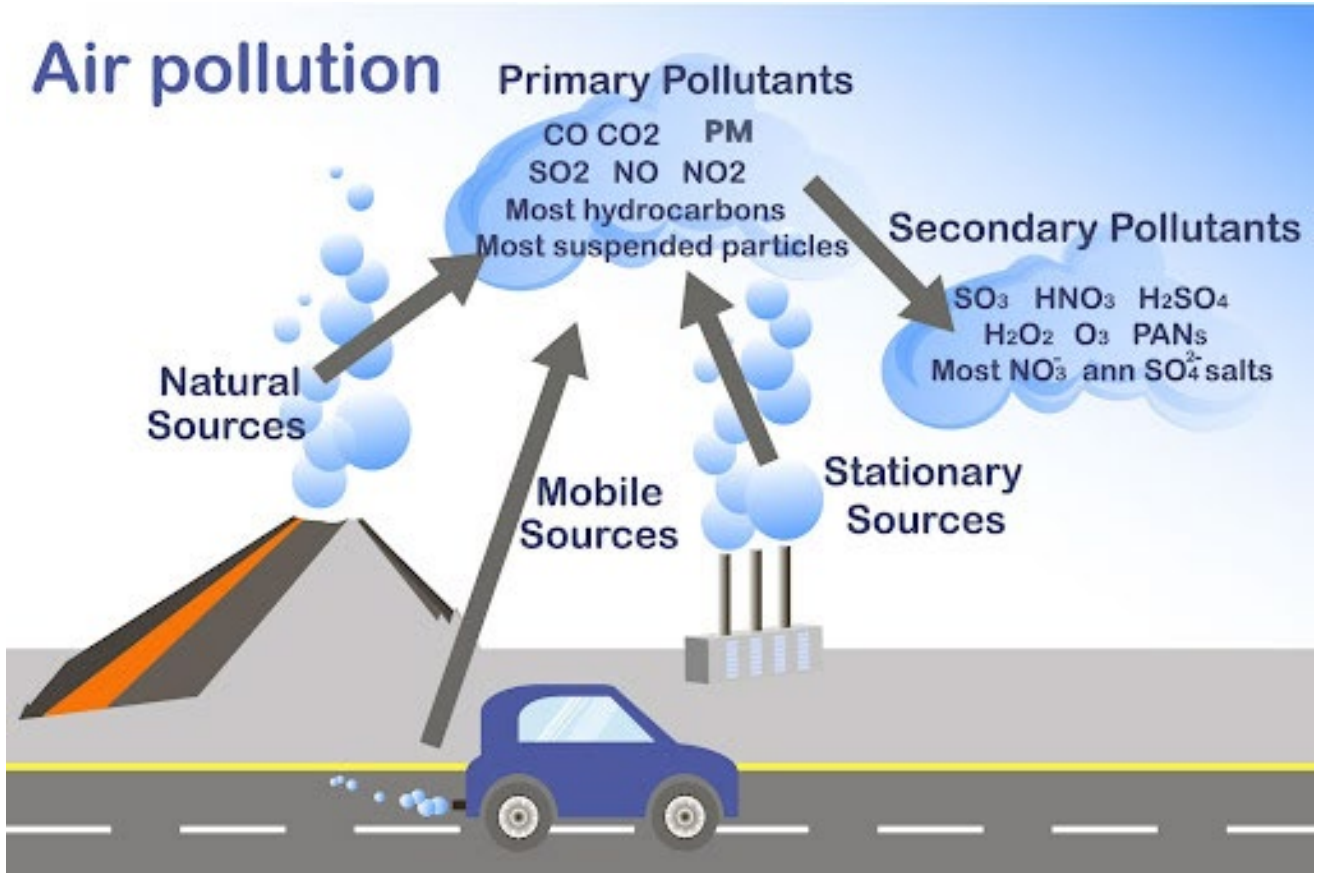
- Reactive species
- Aerosols
- Dust



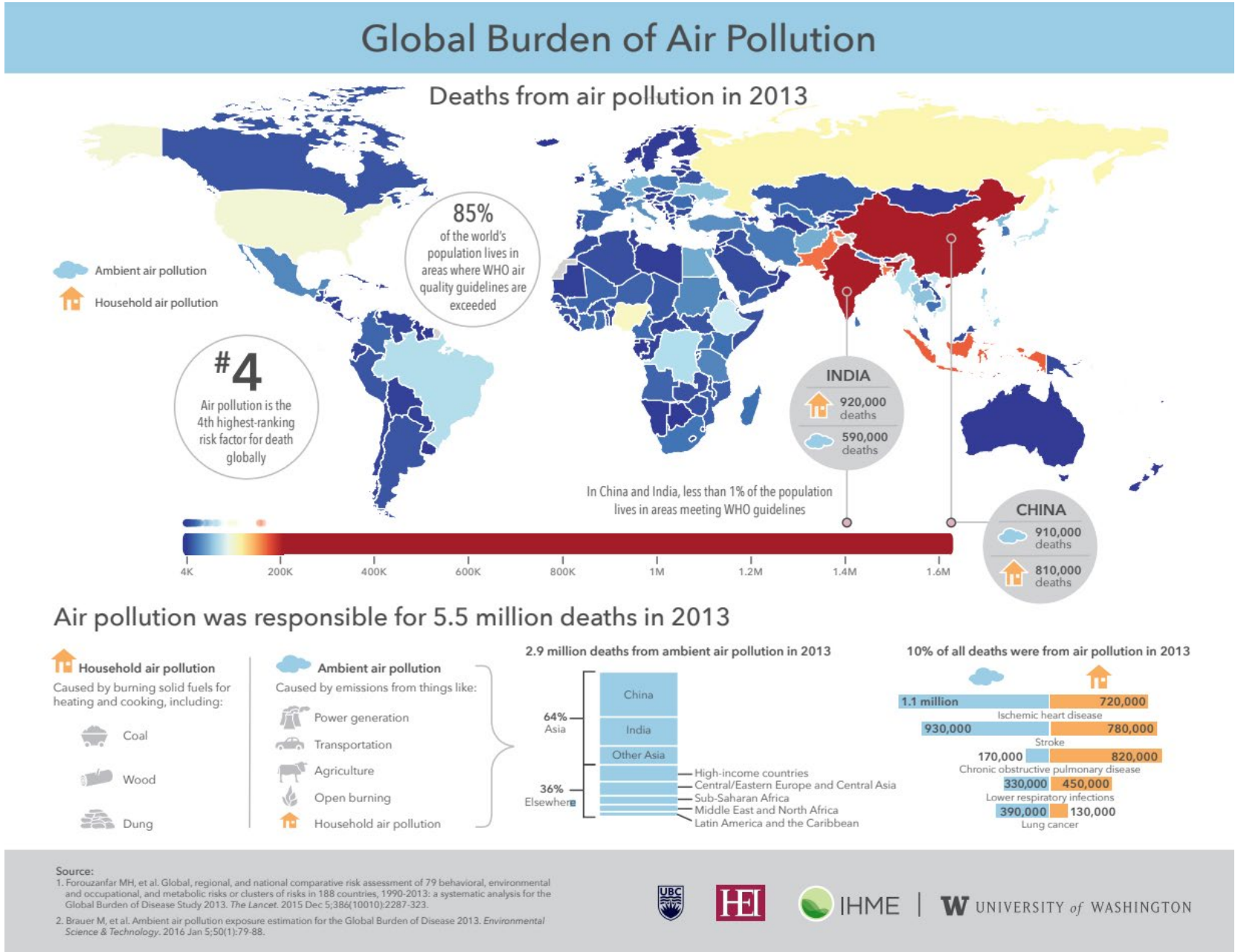
MAQS: the MIT Air Quality Monitor

Why do we care?

- Harms human health
- Damages ecosystem
- Contributes to climate change



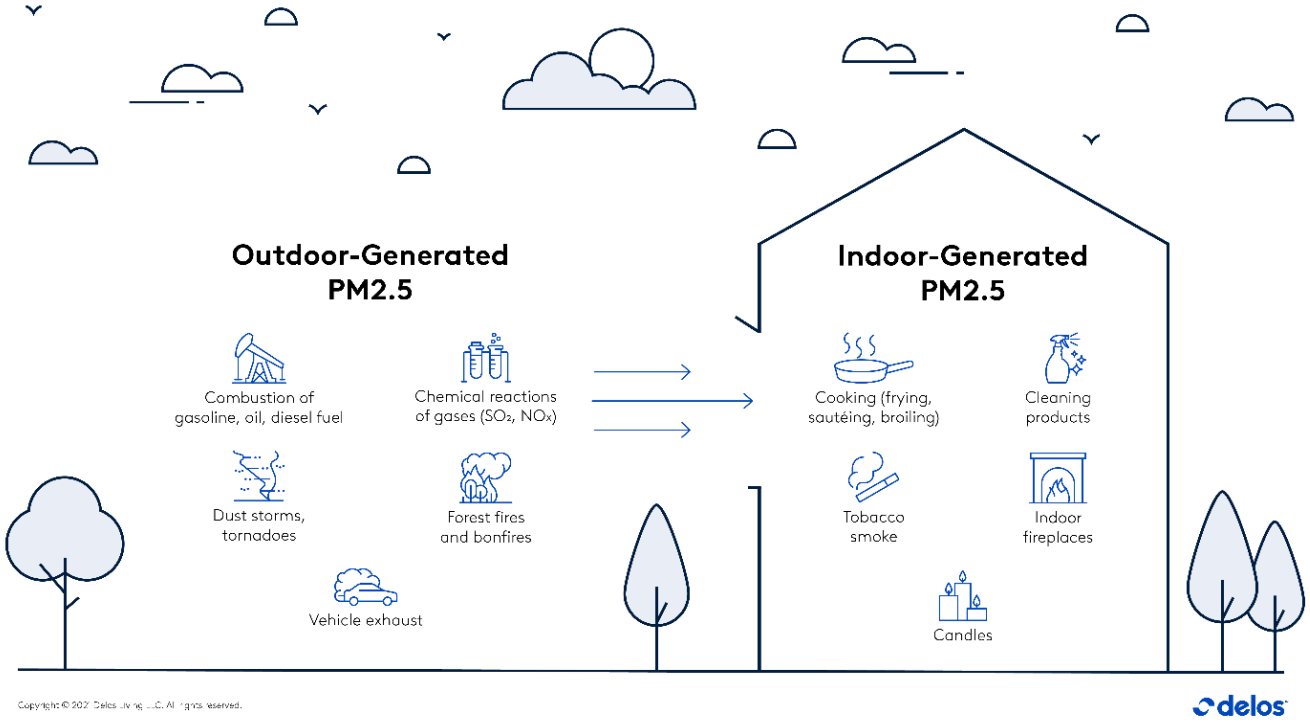
MAQS: the MIT Air Quality Monitor

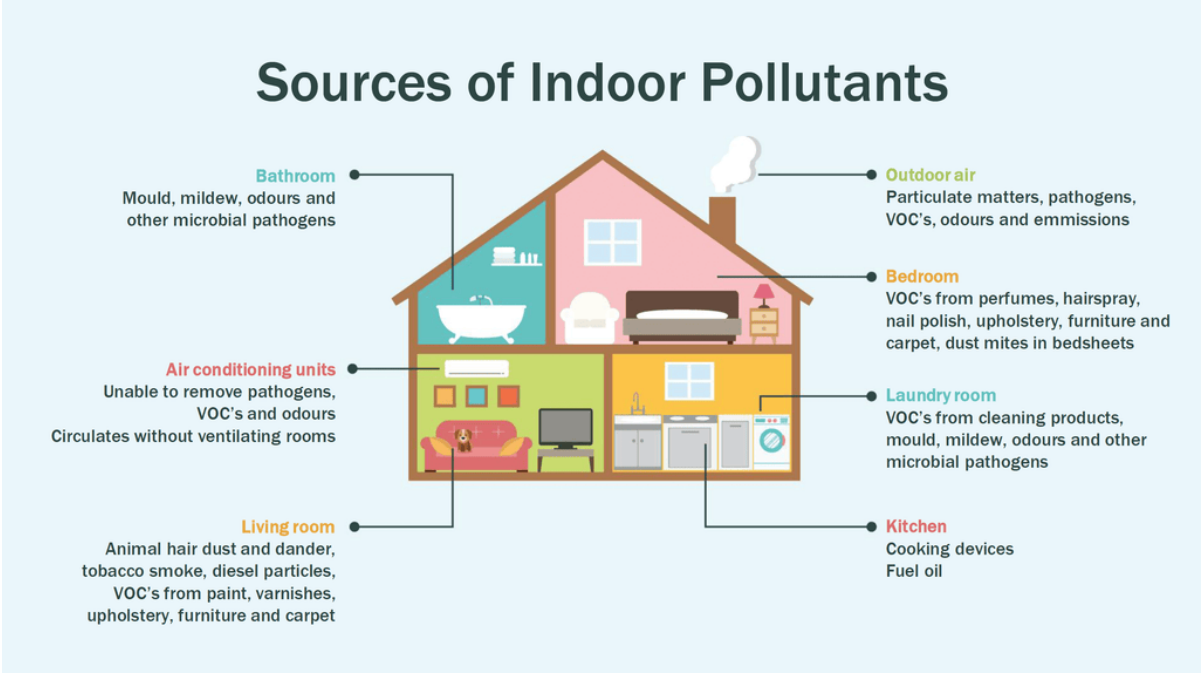


MAQS: the MIT Air Quality Monitor

Indoor and outdoor air quality

- Indoor air is not just outdoor air
- Sources of pollutants differ





MAQS: the MIT Air Quality Monitor

Smoke from Oak Fire prompts Bay Area air quality advisory, chokes Sierra Nevada

California's biggest 2022 wildfire has burned more than 18,000 acres

The Mercury News

JERSEYDALE, CALIFORNIA – JULY 24: A column of smoke rises above the Oak Fire on July 24, 2022 near Jerseydale, California. The fast moving Oak Fire burning

THE CLIMATE 202

Gas stove pollution causes 12.7% of childhood asthma, study finds

Analysis by Maxine Joselow
with research by Vanessa Montalbano

January 6, 2023 at 7:30 a.m. EST

The Washington Post
Democracy Dies in Darkness

MAQS: the MIT Air Quality Monitor

Calls for post-Covid 'revolution' in building air quality

BBC

14 May 2021 · Comments

Coronavirus pandemic

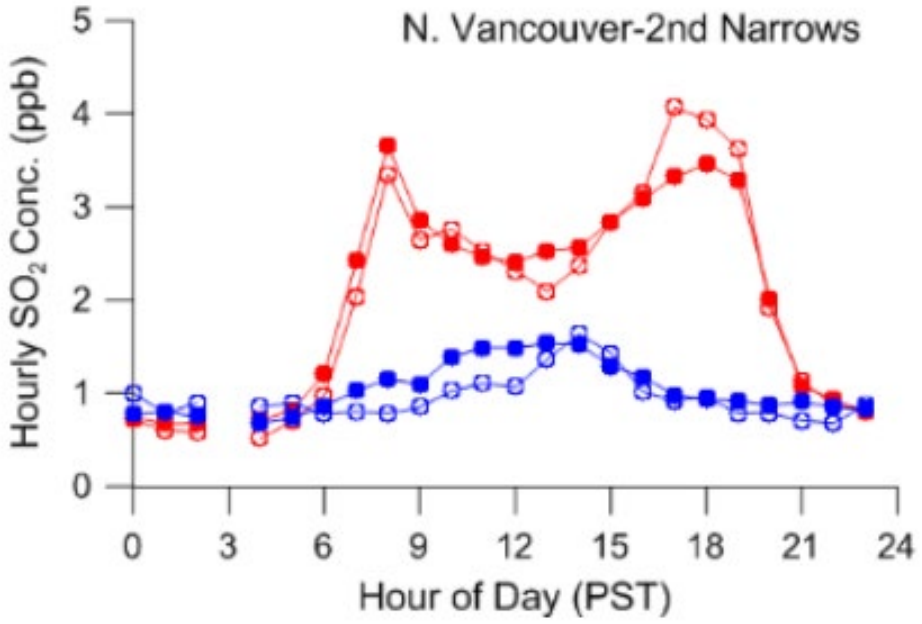
MAQS: the MIT Air Quality Monitor

Why measure?

- We can do something about it
  - Clean air, turn on fan, open window, etc.
  - Inform policy, legislation
- We can learn about health effects
  - Measure exposures, correlate to outcomes
  - Beyond zip-code level, can we get to street-level, building-level, personal exposure monitoring?

MAQS: the MIT Air Quality Monitor

- Why measure locally, frequently?
  - Air quality can change block by block, and hour by hour
  - Get to accurate & precise exposure monitoring



North Vancouver–Moodyville Air Quality Monitoring Study (2016)

Apte Research Group

MAQS: the MIT Air Quality Monitor

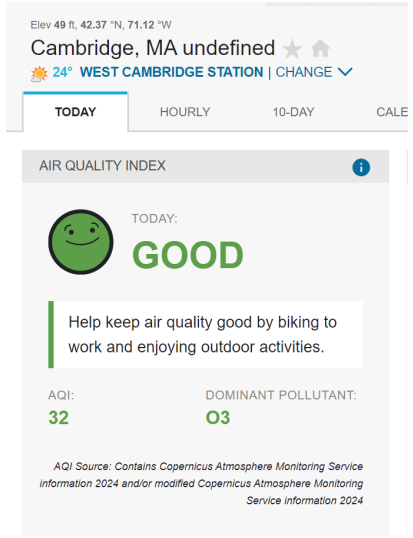
What exactly are we trying to measure?

- Multiple classes: **primarily arise primarily from combustion: cars, trucks, tobacco smoke, cooking, etc.**
  - Nitrogen oxides (NO_x: NO + NO_2)
  - Sulfur dioxide (SO_2)
  - Particulate matter (PM)
    - Complex mixture of solid and liquid particles of organic and inorganic substances suspended in the air
    - Are also derived via reactions of SO_2, NO_x, etc.
    - Classified by size
      - PM_{10} : particles with a diameter of 10 microns or less
      - $PM_{2.5}$ particles with a diameter of 2.5 microns or less
  - Volatile organic compounds (VOCs)
    - Higher indoors
    - Acetone, benzene, formaldehyde, etc.
  - Ozone O_3
    - Arises via reaction of sunlight + volatile organic compounds (VOCs) and NOx
  - Carbon monoxide (CO)

That's a lot of stuff to measure…

MAQS: the MIT Air Quality Monitor

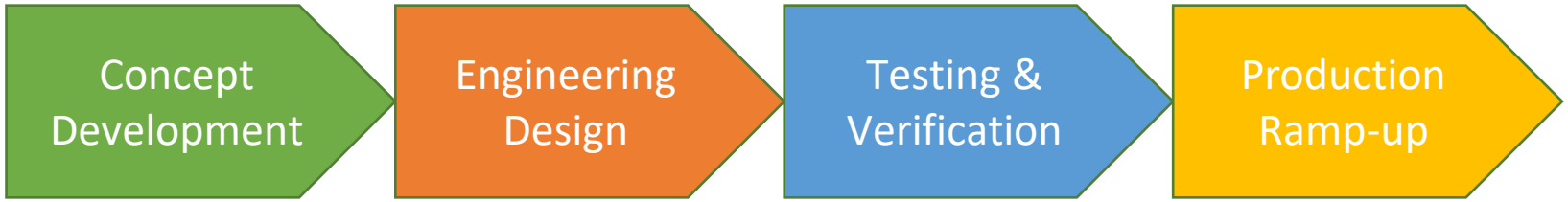
- Need to condense down into simple metric that *people* can understand: air quality index (**AQI**) ➔ scalar rather than vector
- Overall agreed-upon metric for reporting air quality
  - Comprised of $PM_{2.5}$, PM_{10}, NO_2, SO_2, CO, O_3 [1h & 8h]
  - Quantities averaged over 1h, 8h, 24h
  - Piecewise-linear model for each pollutant
  - Overall AQI = highest (worst) AQI of all measures



Category	AQI	$PM_{2.5}$ ($\mu g/m^3$) 24hr avg	PM_{10} ($\mu g/m^3$) 24hr avg	NO_2 (ppb) 1hr avg	SO_2 (ppb) 1hr avg	CO (ppm) 8hr avg	O_3 (ppb) 8hr avg	O_3 (ppb) 1hr avg
Good	0--50	0--12.0	0--54	0--53	0--35	0--4.4	0--54	-
Moderate	51--100	12.1--35.4	55--154	54--100	36--75	4.5--9.4	55--70	-
Unhealthy for Sensitive Groups	101--150	35.5--55.4	155--254	101--360	76--185	9.5--12.4	71--85	125--164
Unhealthy	151--200	55.5--150.4	255--354	361--649	186--304	12.5--15.4	86--105	165--204
Very Unhealthy	201--300	150.5--250.4	355--424	650--1249	305--604	15.5--30.4	106--200	205--404
Hazardous	301--500	250.5--500.4	425--604	1250--2049	605--1004	30.5--50.4	-	405--604

https://blue.cs.sonoma.edu/cs115/F17/proj/p1/cs115_p1.html

MAQS: concept development



- Concept development: identify requirements, establish target specifications, generate concepts, prototyping (as needed), refine and select most promising concept
- Requirements [needs]
  - Focus on **what** the system should do**,** rather than **how** to do it
- Identify requirements: who's requirements? ➔ stakeholders' requirements
- Stakeholders: the people affected by your product
  - Customer, end-user ➔ these often most important
  - But also retailer, employee, installer, etc.

Stakeholders

Customers are not always end-users…

ICU monitor

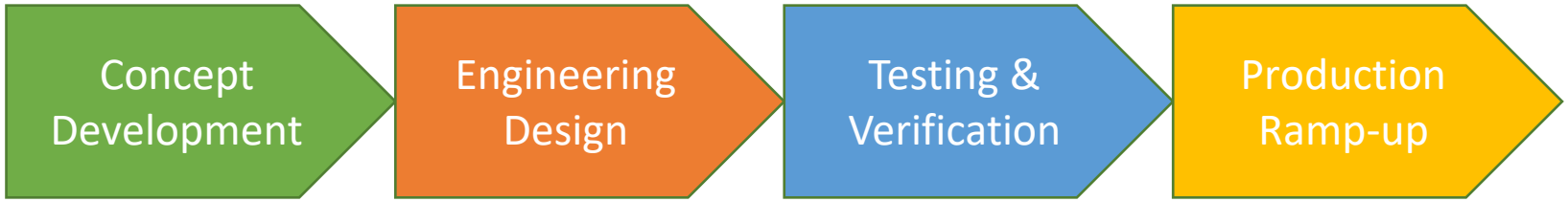
Hospital procurement

Customer

End-user

Stakeholder

MAQS: concept development



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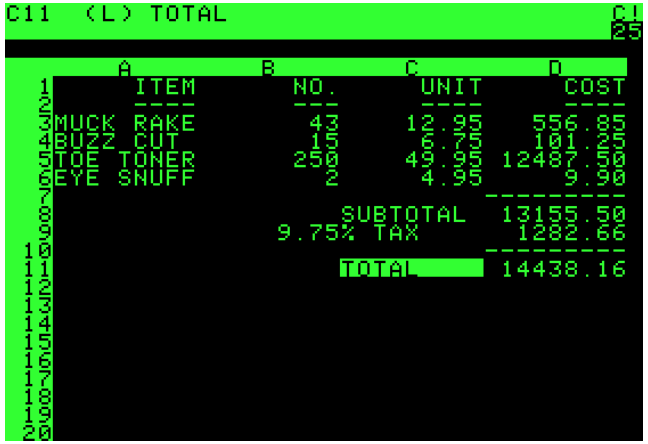
  - Customer, end-user ➔ these often most important
  - But also retailer, employee, installer, etc.
- For MAQS, stakeholders are 6.900 staff, 6.900 students, EDS staff

MAQS: requirements

- Talk with stakeholders (esp. customers and end-users)
- Assemble list of requirements
- If extensive, organize into hierarchy
- Prioritize
  - Must have *vs.* Should have *vs.* Might have
  - ***, **, *
- Sometimes the customer doesn't know what they want – *latent* need



MAQS: requirements

We developed requirements based on internal staff discussions and talking with EDS staff

Why not with students?

1. It should accurately measure indoor air quality **
2. It should be portable ***
3. It should be possible to get the data off the device **
4. It should be a useful pedagogical exercise ***
5. It should maintain privacy *
6. It should be low cost *
7. It should be rugged and robust **
8. Multiple systems should be able to be used simultaneously ***
9. It should be easy to view the current and past data **
10. It should leverage MIT facilities **

Closing thoughts

- Thursday we'll talk in detail about the project
- Next week we'll start continue down the HW/SW design pathway
- Tomorrow is our first lab!