A Vision for Mid-Century Sustainable Urban Transportation

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Tyler C. Folsom
University of Washington
Bothell, WA

This version has embedded videos replaced by links to limit the size

Why Transportation?

- At 29%, Transportation is the largest segment contributing to green house gases (GHG)
- Transportation GHG comes from petroleum:
  - 58% cars (gasoline)
  - 23% trucks (diesel)
  - 8% planes (jet fuel)
- There are feasible methods to reduce GHG for other sectors: Electricity, Buildings, Industry

Why Urban Transportation?

- Americans drive over 3 trillion miles a year
- 2/3 of those miles are urban
- The average urban trip is 12 miles
- Average speeds with cities are in the 10-25 mph range.
- Eliminating GHG on 1T miles of short urban travel would cut U.S. GHG by 6%

Short Urban Trips

- 1.5 person average US car occupancy
- Bikes or e-bikes could handle all the short trips
- This works in Amsterdam, but let's try something high tech for Americans
- Build something that is more convenient, faster, safer and less expensive.
- And make it use as little energy as possible.

IEEE Vehicular Technology Society

hereby presents the

Bronze Award

to

Tyler Folsom

For their video titled, "Looking Back" in the 2023 VTS Tales of Tomorrow Competition

THE INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS, INC.
FOUNDED
NEW YORK
1884

Weihua Zhuang
President
IEEE Vehicular Technology Society

IEEE VTS
Connecting the Mobile World

2023

https://www.youtube.com/watch?v=ni1zu3A_lDg

This 10-minute video gives the vision for future urban transportation.

The rest of the talk explains why these technologies are important and how to get there

Energy to move a vehicle

$$E = k_1 v C_R \sum m + k_2 v^3 A\, C_D$$

<u>Rolling Resistance</u>
Velocity
Mass
Rolling coefficient

<u>Aerodynamic Drag</u>
Velocity cubed
Frontal area
Drag coefficient

For automobiles, Rolling = Drag @ 55 km/h (35 mph)
For bicycles, Rolling = Drag @ 20 km/h (12 mph)

Energy to overcome rolling resistance

$$\frac{dW_R}{dt} = \frac{v\sum m}{\eta} g\left[C_R + \frac{s}{100} + \frac{a}{g}\left(1 + \frac{m_W}{\sum m}\right)\right]$$

slope acceleration

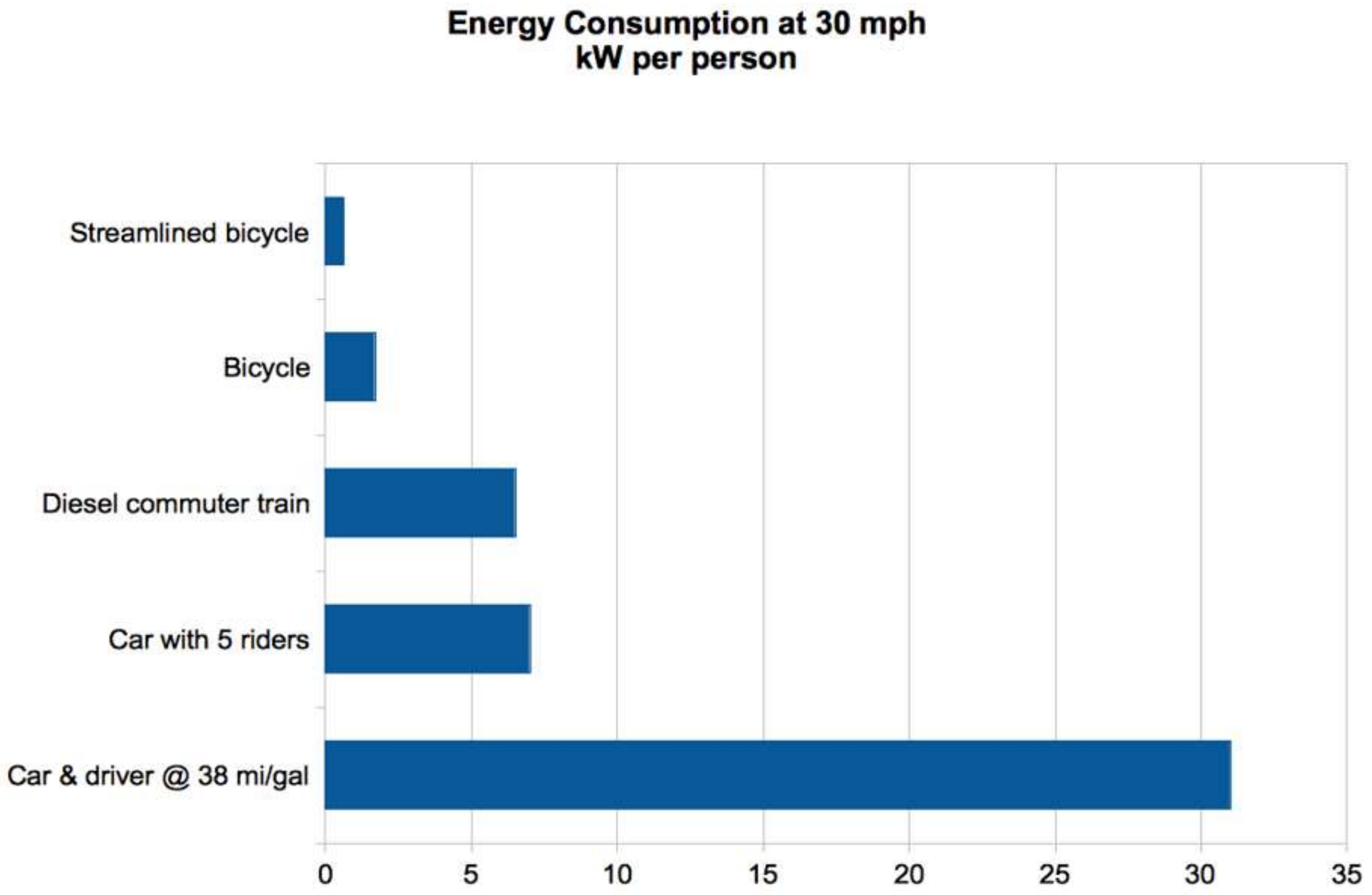
Simplified equation omitted slope and acceleration.

There is an energy penalty for stop and go.

Acceleration is multiplied by 1 + ratio of wheel mass to total mass.

Heavy wheels impede acceleration.

“No Brainer”
Light vehicles use 30x less energy



D.G. Wilson, Bicycling Science, 3rd ed. MIT Press, 2004, pp. 140, 166

“Old EVs were dinosaurs”
Typical Electric Vehicle Weights (lb.)

Vehicle	Weight	Battery Weight	Riders	Rider Weight	Vehicle/ Riders
Ancheer e-bike	55	7.5	1	180	0.3
Organic Transit ELF enclosed trike	160	20	1	180	0.9
Tesla Model S	4,250	1200	1.5	270	15.7
Ford F150	6,015	1800	1.5	270	22.3
Proterra ZX5 Max bus	33,350		10	1800	18.5

- Electric cars may be too heavy to be sustainable.

Farhad Manjoo, *The One Big Problem with Electric Cars*, New York Times, Feb 19, 2021
https://bikegrade.com/how-much-do-ebike-batteries-weigh/
https://motorandwheels.com/electric-car-batteries-weight/
https://www.thedrive.com/news/this-electric-bus-has-a-battery-pack-over-3-times-bigger-than-a-hummer-evs

Swapping heavy batteries is impractical

- Batteries for bikes and trikes are light enough to swap.
- Battery swap stations are in use in Nairobi.
- An automated light vehicle can take itself to a refueling station when it senses low charge.
- Batteries can be quickly swapped by robot

PBS Video Clip

- https://www.kcts9.org/show/reinventors/episode/self-driving-bikes-seattles-next-transit-revolution-2gfwzw
- 1:15 to 2:12

“No more dinosaur juice” Renewable Energy

- Pods use a 15-44 lb. (7-20 kg) battery vs. 220-1200 lb. (100 - 544 kg) for automobiles
- Battery is sufficient for 20 mi (30 km) range
- When battery charge is low, pod takes itself to a station for battery swap and is quickly in service again
- Wind or solar at charging stations runs system on renewable energy
- Batteries can be recharged at any time of day

Energy to overcome drag

$$\frac{dW_D}{dt} = \frac{v}{2\eta} A\rho C_D (v + w)^2$$

We have little control over

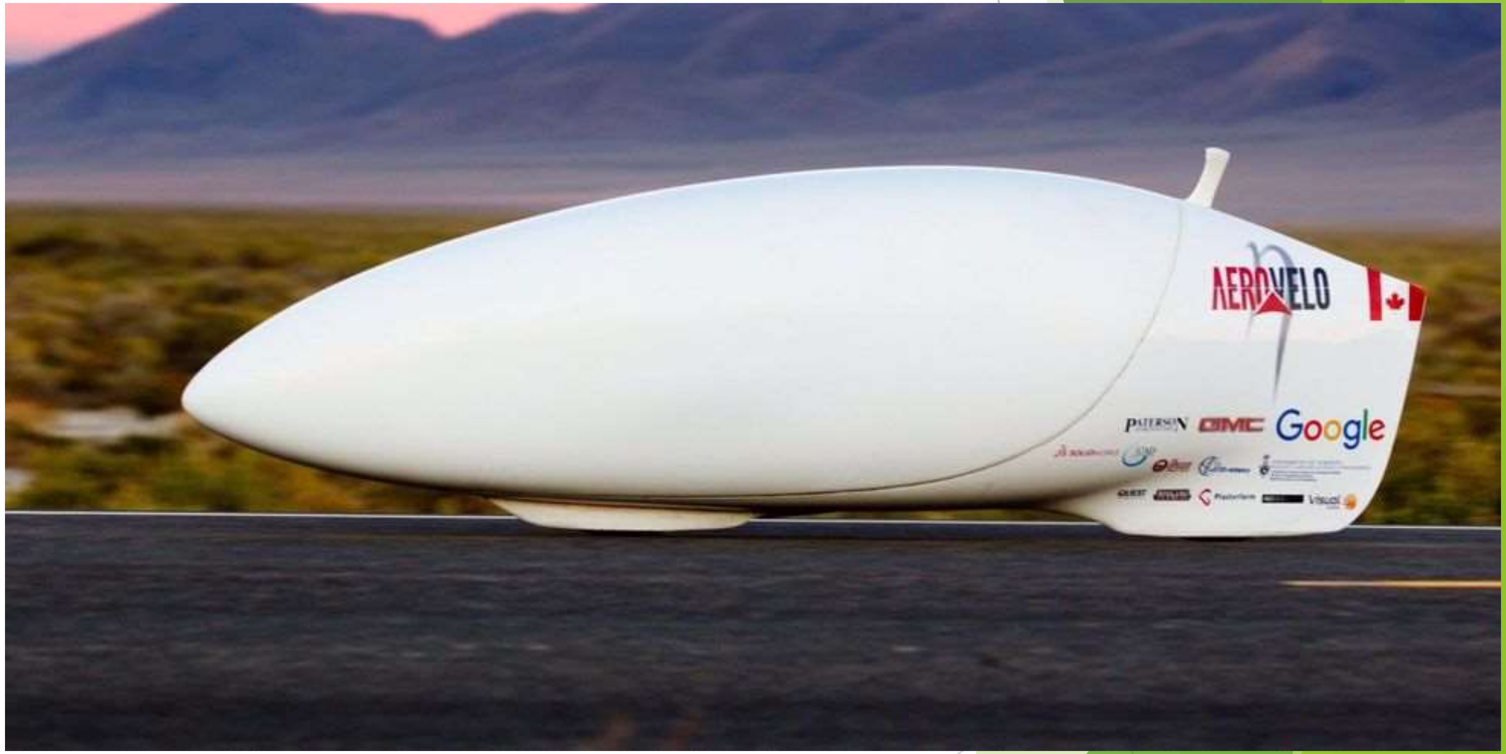
- ρ: air density
- η: mechanical efficiency of transmission
- w: wind speed

We can control

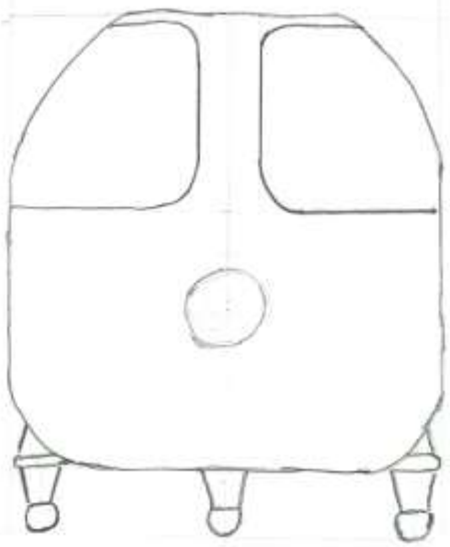
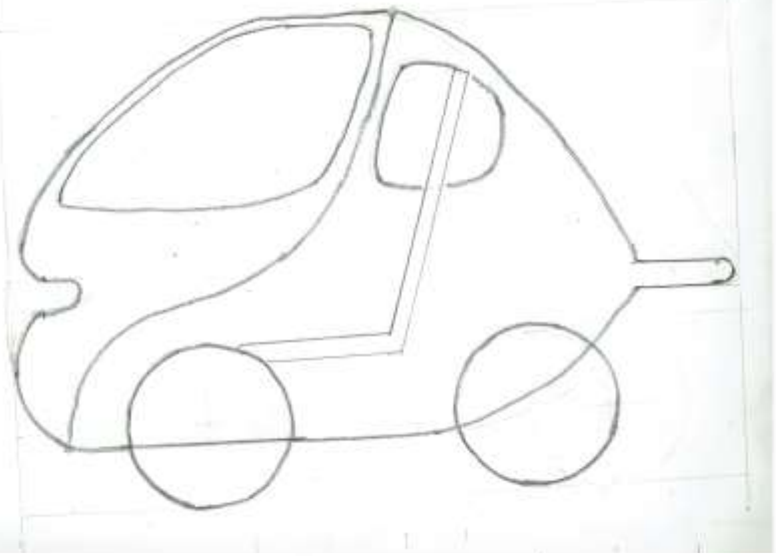
- A: frontal area
- C_D: drag coefficient (streamlining)
- v: velocity

Human powered speed record

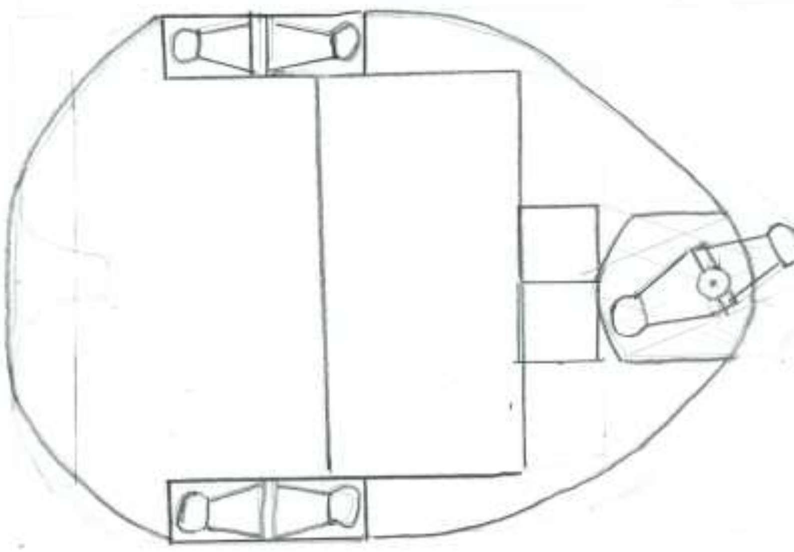
- 89.59 mph (144.2 km/h) on human power alone
- Timed over 200 m trap from running start
- No wind or slope
- Not a practical vehicle



Light vehicles need to be aerodynamic

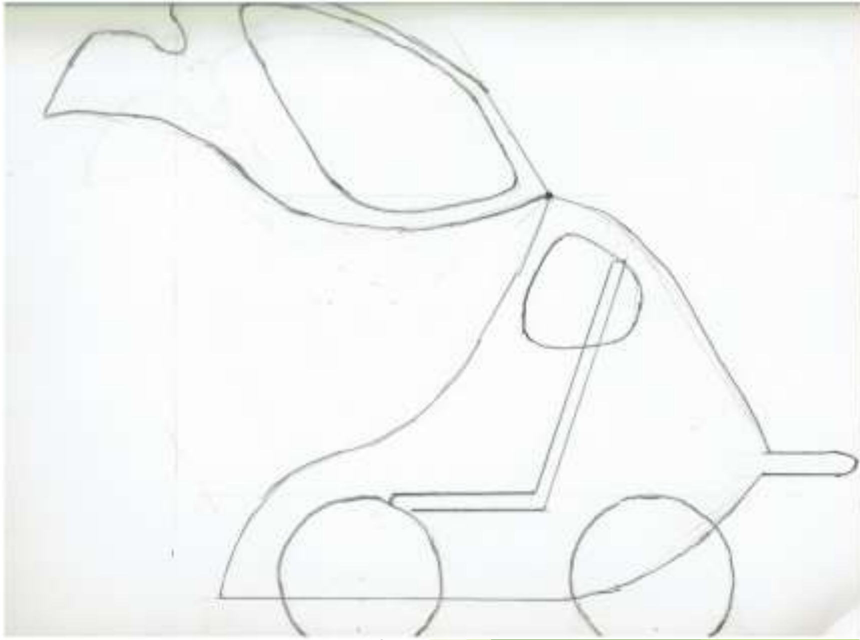
- The vehicles in the video were from an available asset
- The preferred vehicle is lighter and more streamlined
- It could be a rear-steering trike
- Non-moving front wheels allow for better aerodynamics and a seat wide enough for two people



Vehicles would be ADA compliant

- The vehicle door swings up for front entry
- There are two versions in use

1) Standard: Seat for two riders
2) Cargo: No seat. When open a ramp allows loading a wheelchair or roller bag.



"Just call a pod and go"
Mobility as a Service (MaaS)

- There will be no need to buy and maintain your own vehicle
- Use your cell phone to summon vehicle(s) as needed
- Small pods couple together to form bigger vehicle
- Public transportation with no schedule or route constraints
- Privately owned vehicle interoperate with public vehicles

“Systems are the key; everyone had to stop” No Stop and Go

- City boulevards will carry an elevated guideway as wide as today’s single lane.
- The elevated lanes are only for ultra-light vehicles.
- Light vehicles fit in a half lane.
- There is a entry/exit elevated lane and a through lane.
- Vehicles in the through lane never stop and only slightly change speed.
- City streets can be used by ultra-lights, cars and trucks.

Platooning

- Automated vehicles are most efficient when operating in platoons.
- Platoons are separated by enough distance for safety
- There might be up to 25 in a platoon
- Within a platoon, gaps might be a few meters
- Shrinking the gap between vehicles saves energy
- However, when the following distance gets too small, the ride becomes jerky
- Vehicles wind up constantly changing speed to maintain a small gap

Bumper to bumper at 30 mph

- Shrink the gap between vehicles to zero and let them mechanically couple.
- The coupling mechanism has a strong spring that absorbs the jerks and smooths the ride.
- Pods in the through lane move at a constant 30 mph ±3 mph
- New vehicles can join a platoon
- When pods bump into each other, they couple

“Not talking to each other” Communication System

- All vehicles are connected by wireless
- Use either cellular V2V or dedicated short range communication (DSRC 802.11p)
- Physically connected vehicles have CAN wires in the couple
- Within a platoon, no wireless latency or security concerns
- All platooning behavior is externally controlled

“Bad traffic management”
No drivers

- Sophisticated control system within a platoon
- No towing or pushing
- Each pod is independently powered and steered
- Each pod knows its precise relative position and planned acceleration
- Each vehicle has a CAN bus to send behaviors to actuators
- The CAN bus is shared; each vehicle knows others’ motions before they happen
- External control of when vehicle can enter guideway and merge
- Not allowed to enter if system is at capacity

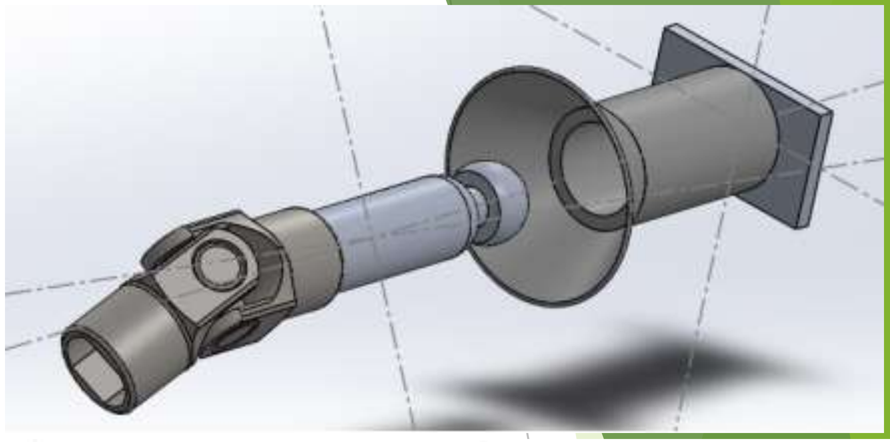
“Half the length and width; less pavement; more trees”

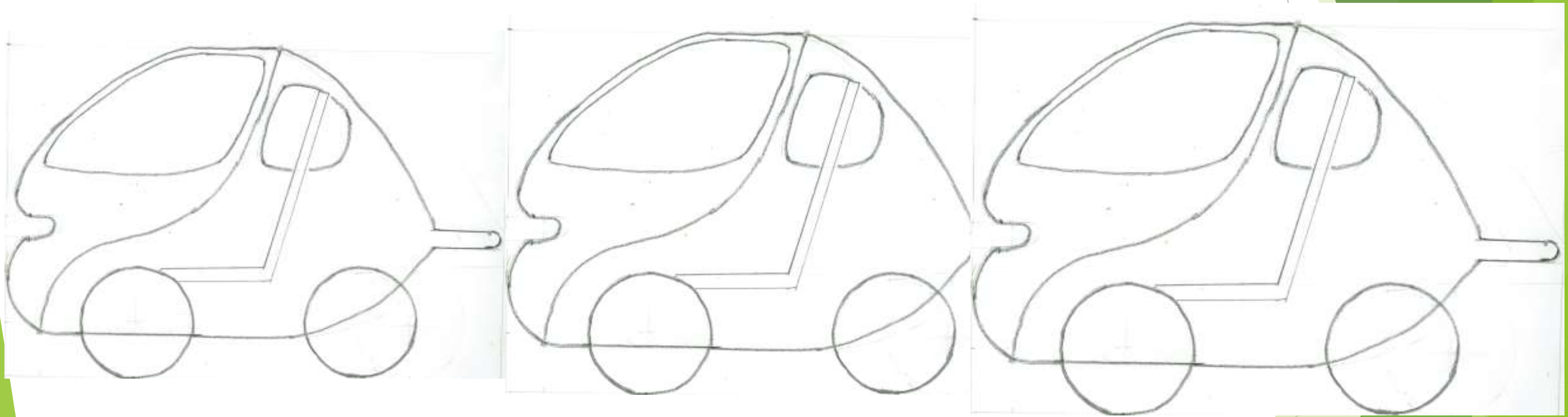
- Pod is 4.5’ (135 cm) wide and operates in a 5’ (150 cm) wide lane
- Video has more pavement than needed on the guideway.
- Elevated guideway would be 10’ wide, one way
- Guideway has a through lane and an exit / merge lane
- Pods are 5’ (160 cm) high; guideway can be topped with solar panels
- Panels would provide shade and intercept rain or snow

“People bought bigger pods than needed” Vehicles are right-sized

- Today, people buy a vehicle big enough to haul all the people and cargo they might need.
- Often it just carries the driver.
- New vehicles would be modular.
- Each carries two people or cargo.
- If you want to carry five people and gear, combine four vehicles

Modular by Coupling

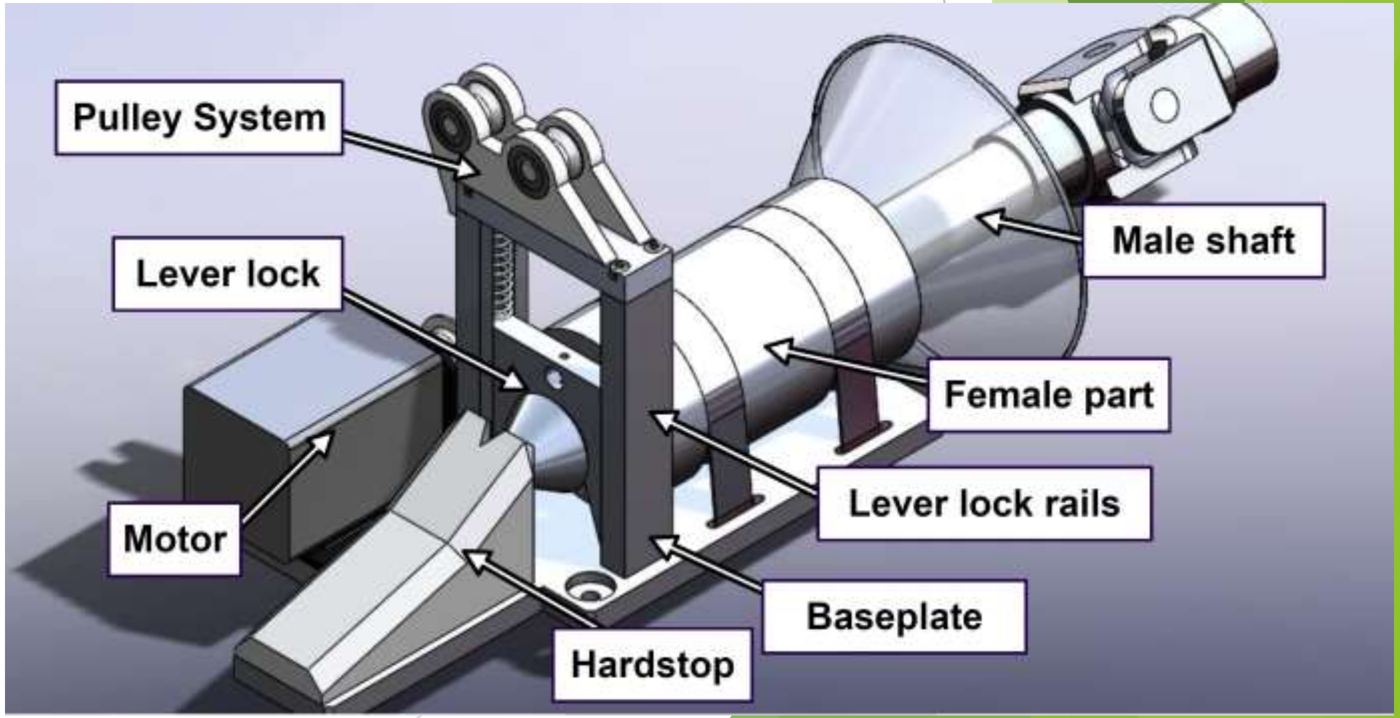




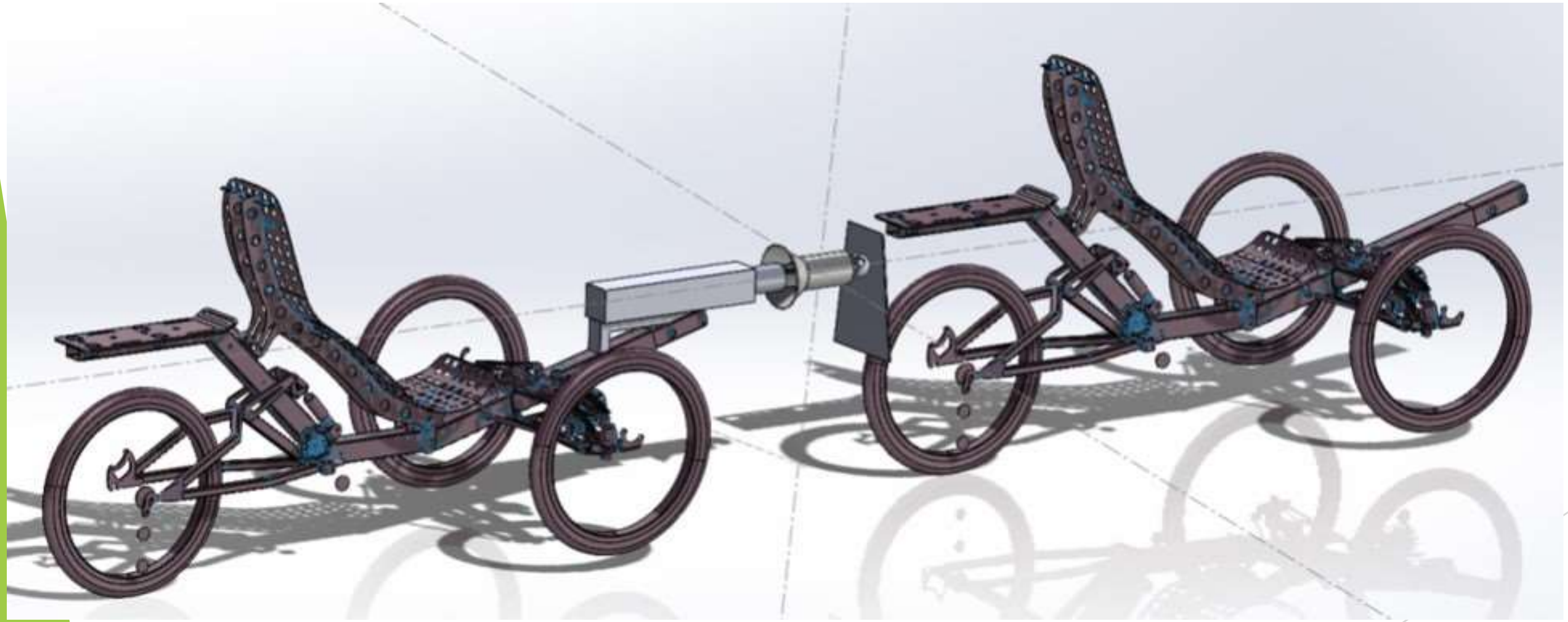
- Pod ends with a flexible shaft on a shock absorber
- The front end of the vehicle is a funnel directing the shaft
- When vehicles collide they automatically couple based on mechanical design

Decoupling at speed

- A pod can release its couple while moving.
- A microcontroller pulls up the lever lock.
- Vehicles can then separate

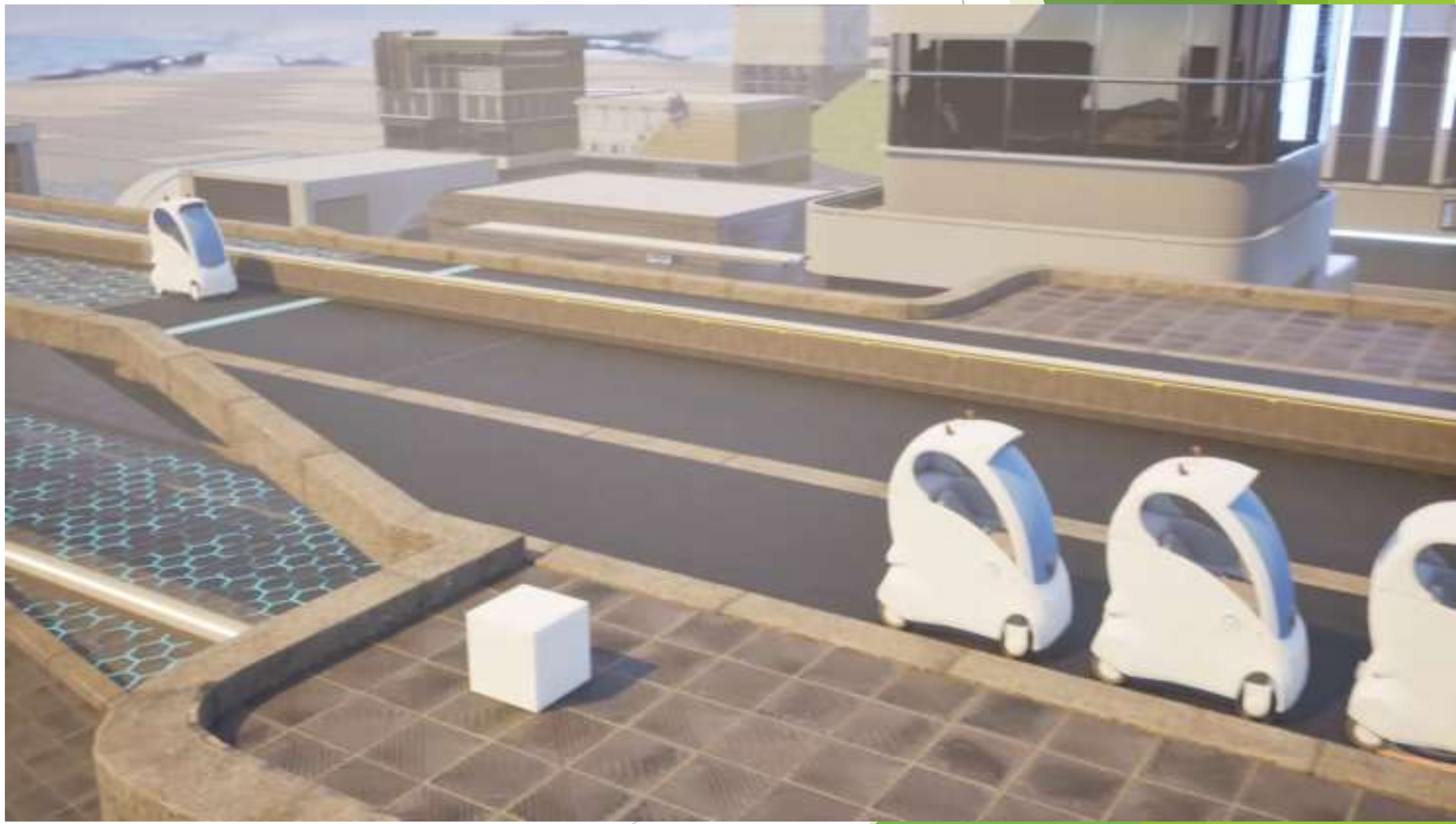


Prototype Demonstration



Merging into Platoon

- Platoon approaches parked pods
- Pods joining accelerate before platoon arrives
- New pods are up to speed when platoon passes
- Merge from acceleration lane to through lane
- Couple onto platoon while moving
- Lanes would be narrower than in animation



Complex Merge

- All vehicle are sorted by destination
- Longest destinations in front
- As platoon approaches merge point, it opens gaps for merging pods
- Joining pods fill those spaces
- Pods fill gaps and reconnect
- Exiting pods separate from rear

Standards need to change

- ASCE Automated People Mover standard does not allow coupling / decoupling while in motion
- The standard assumes that closely spaced vehicles have a hazard condition of colliding
- These vehicles are designed to safely couple when they bump into each other
- Collisions produce no damage

"12,500 vehicles per hour"
System Capacity: not quite

- Today's typical freeway lane can handle 2300 vehicles per hour
- Pods are 8' (2.4 m) long
- They operate in platoons of 1-25 vehicles with a gap of 6 seconds or more between platoons
- Full capacity: system is maxed out with platoons of 25 pods
- Platoon length is 25 * 2.4 = 60 meters
- @ 50 km/hr (= 13.9 m/s) a platoon passes every 4.3 s
- 25 vehicles every 10.3 seconds
- 349 platoons in an hour
- **8,725 vehicles per hour**

“People used to spend a lot on transportation”

- Today, electricity for cars is about equivalent to $1/gal, but getting cheaper
- Target price of light fully automated pod is $10,000
- Compare to $20k - $110K for partially automated car
- 25 pods replace a $750,000 electric bus
- Main transit operating costs of fuel and driver salary are gone
- No need to subsidize public transportation

“Trains doing 200 – 400 klicks [km/h]” Intercity Travel

- Ultra-light vehicles serve high speed rail stations.
- 30 mph is for travel in the city
- There can be a merge lane from the boulevard to a 60 mph freeway lane
- If all freeway vehicles are automated and accidents rare, light vehicles will be safe
- A 2000 to 4000 pound car can be used for rural areas

Freight

- Steel wheels on steel rails use less energy than rubber tires on pavement
- Rail is more energy efficient than trucks
- Shippers prefer trucks because they are easy to schedule
- Today most rail business is hauling fossil fuel: coal and oil
- When fossil fuels go away, railroads will need to get more flexible and provide service competitive with trucks

Air travel

- Short haul air will mostly be replaced by high-speed rail or overnight automated sleeper cars
- Short routes can be handled by electric aircraft
- Longer routes can use sustainable aviation fuel (SAF) produced from biomass

“Inconvenient to pilot a pod”
Synergy: electric & automated vehicles

- Automated vehicles eliminate congestion if they operate in a dedicated lane and can be choreographed by computer.
- With all vehicles automated, accidents become rare.
- Vehicles weigh less than the riders.
- Light aerodynamic vehicles can get 1000 mpgE.
- A 25 lb battery suffices; EV can swap battery in less time than filling a gas tank – no range anxiety.
- With many batteries to recharge, generate electricity whenever the sun shines or the wind blows.

Making the Vision Real

2005 DARPA Grand Challenge

- Autonomous vehicle race: 130 mile across Mohave desert
- Team Sleipnir, Sequim WA
- Kawasaki ATV
- Sebastian Thrun (Stanford) won and was hired by Google

2007 DARPA Urban Challenge

- Drive in Traffic
- Leader of Snowstorm, team from UBC, Canada
- Jeep Cherokee
- Directed by John Meech, Mining Engineering dept.

Cogneta, Inc.

- Four people from Snowstorm incorporated a BC company in 2007 to commercialize autonomy
- Wrote proposals to US and Canadian agencies
- Little awareness at the time
- No results

Elcano Project at UW

https://github.com/elcano/elcano
https://www.elcanoproject.org/wiki/Main_Page

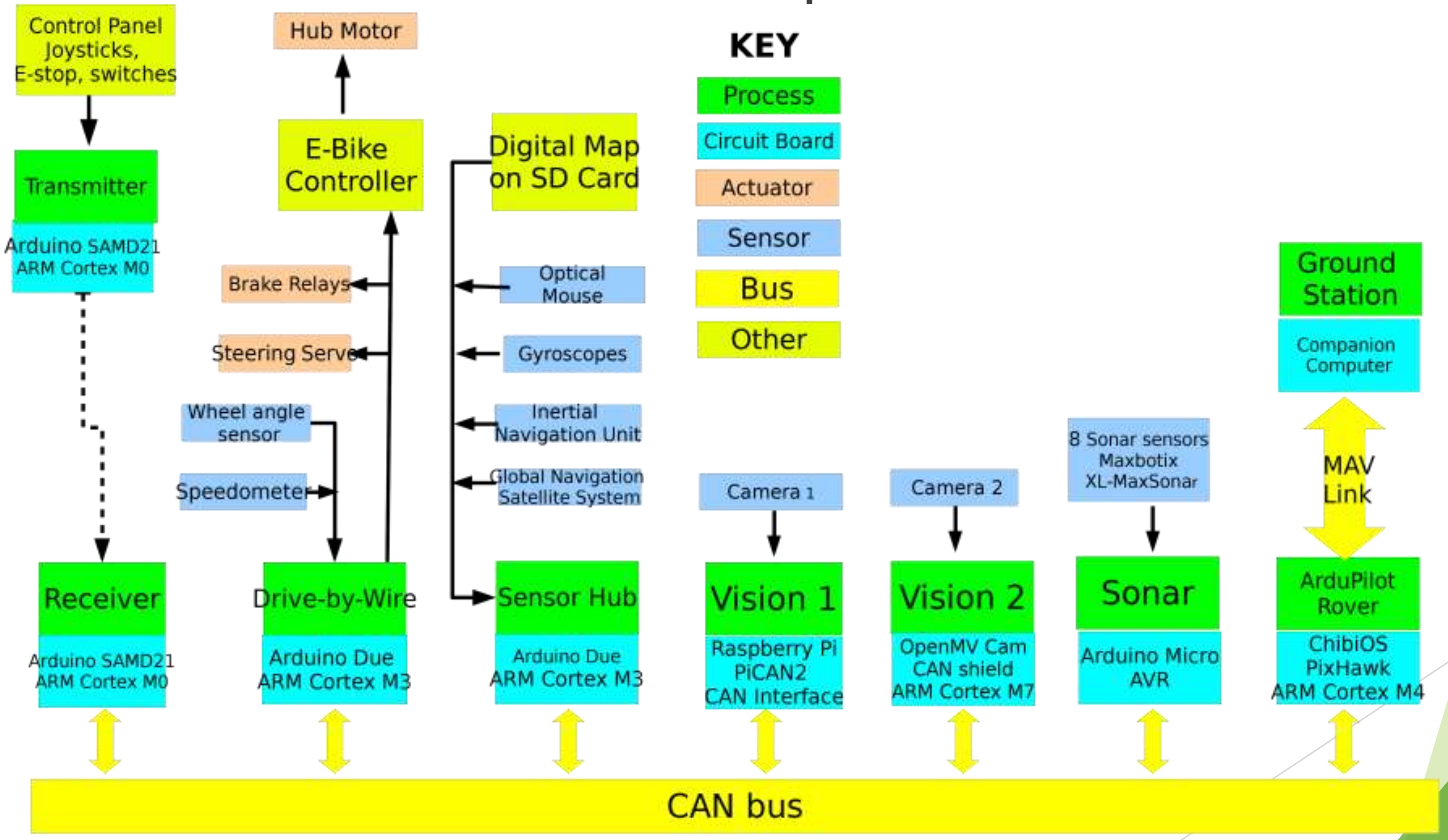
- I scaled the project back to one I could self-fund and take open-source
- Worked with volunteers in makerspace
- UW Bothell picked up the project and hired me in 2013.
- I won a $75,000 grant from Amazon

Video: 1:50 to 2:23
https://www.king5.com/video/entertainment/television/programs/evening/self-driving-tricycle-could-start-a-transportation-transformation-king-5-evening/281-f7a5b332-ad5b-43b4-a53f-89df712a604e

Architecture

Distributed system

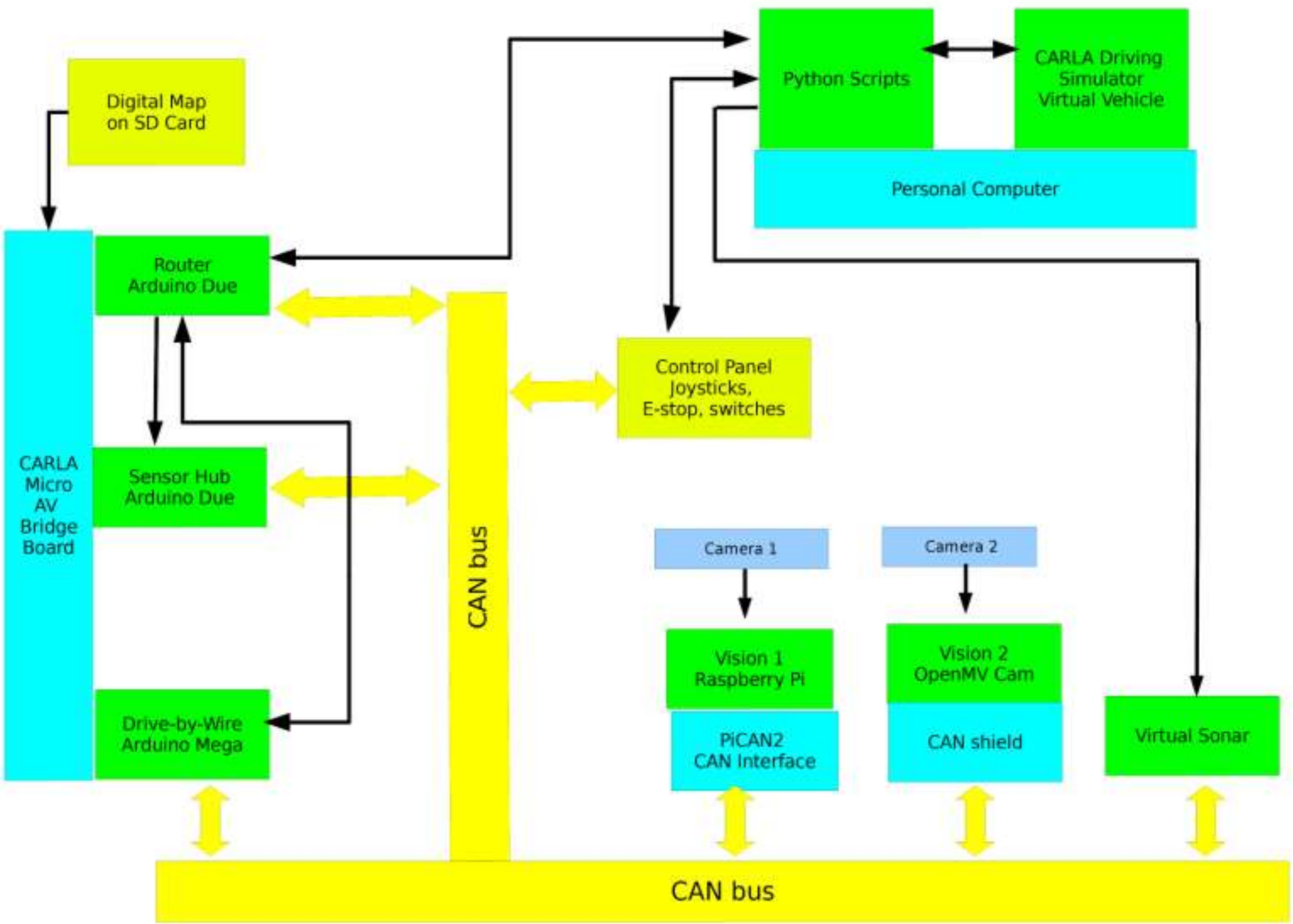
Multiple microcontrollers



Micro-AV SPC

- In 2020 I took advantage of the pandemic and started Micro-AV Social Purpose Corporation: Micro-AV.com
- First product is a simulator bridge with three Arduino Dues
  1. Drive-by-wire controls vehicle actuators
  2. High-Level has sensors for GPS, IMU, etc.
  3. Router sends actuators to simulator & feeds data to sensors
- No need for a vehicle

Simulator Architecture



Get Involved

- We priced the simulator bridge at $500, but there was no demand
- If you can commit to improving code or hardware on https://github.com/elcano/Drive-by-wire
  a limited number of FREE simulator bridges are available

Economics Favors Renewables

Carbon negative by 2050

- A recent peer-reviewed study by the Lawrence Berkeley National Laboratory examined pathways to zero carbon.
- By 2030 they recommend increased wind generation, eliminating coal, more heat pumps in buildings, vehicle electrification, R&D on carbon sequestration, and improving the grid.
- They found that we can reach zero or negative carbon at a cost of $3.5T.
- https://newscenter.lbl.gov/2021/01/27/getting-to-net-zero-and-even-net-negative-is-surprisingly-feasible-and-affordable/

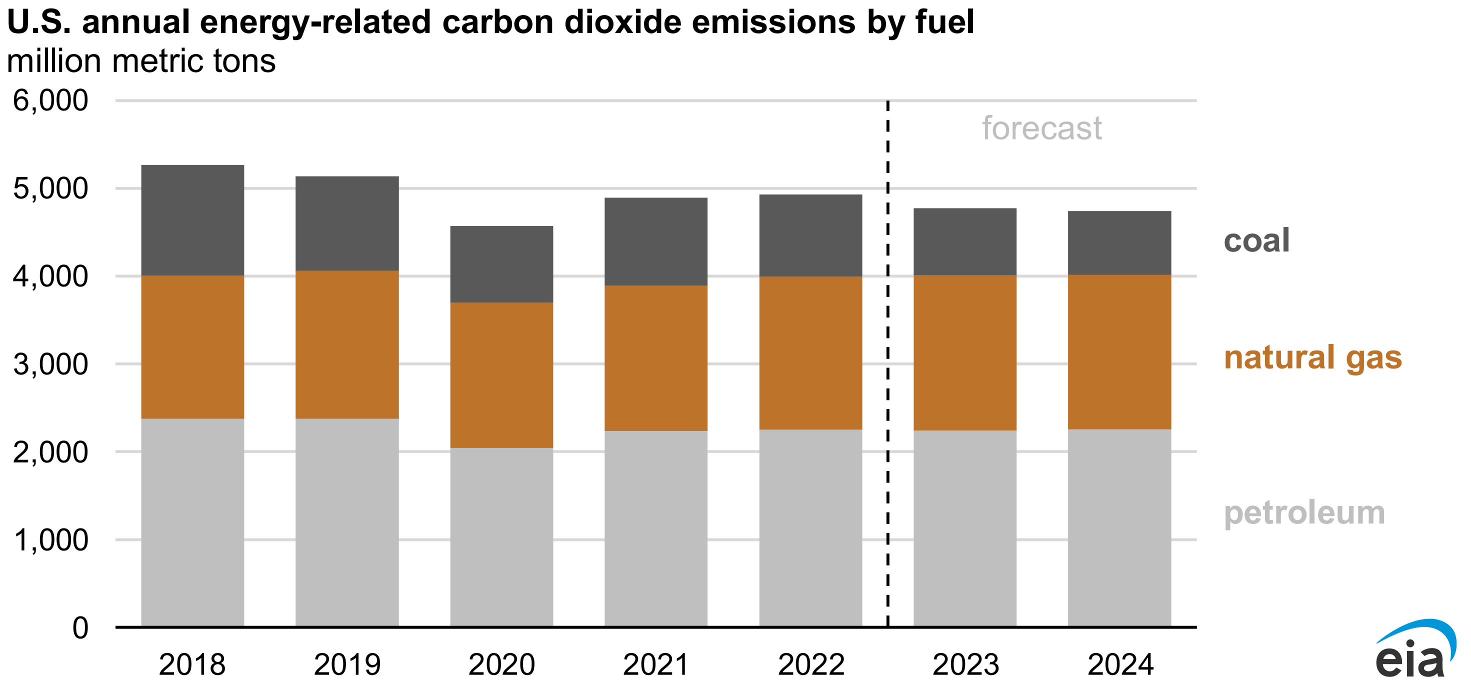
Coal and nuclear are not profitable

- Most coal plants are 40 to 100 years old; at end of design lifetime.
- New plants require pollution mitigation.
- Domestic coal market is shrinking.
- Most nuclear plants are reaching end of designed lifetime.

Renewables are competitive

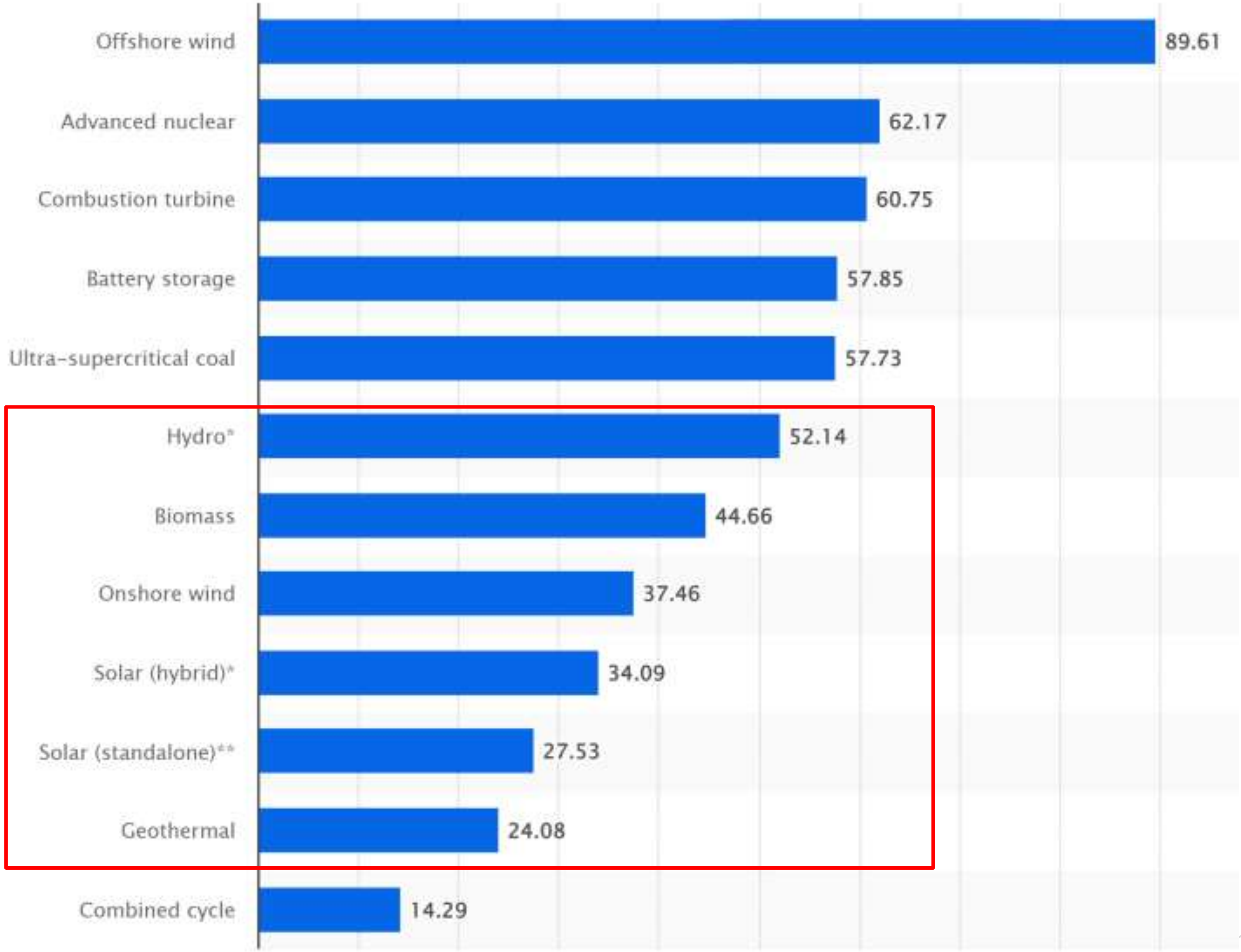
- Cheapest plants to build are natural gas, wind, and hydro.
- Fuel cost of natural gas is $3.60 to $15.45 /MWh; cost for wind and hydro is 0.
- Maintenance costs are lower for natural gas.
- Solar (photovoltaics) is competitive with coal and nuclear.

US CO_2 decreases as coal decreases

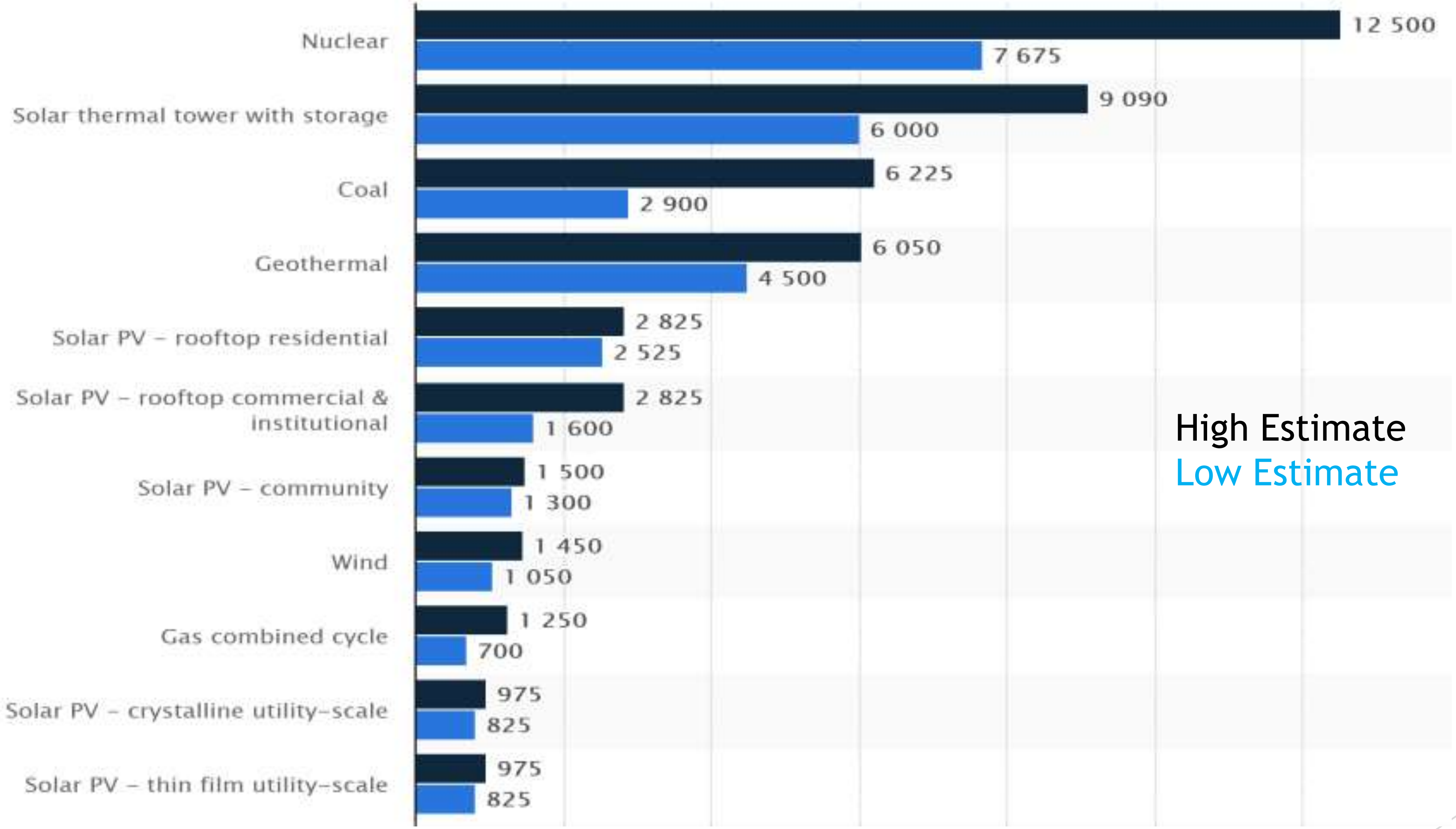


- As coal use decreases, US CO_2 emissions are expected to decline 3% in 2023
- More CO_2 decline predicted for 2024.

Estimated US cost of electricity from new power plants for 2028

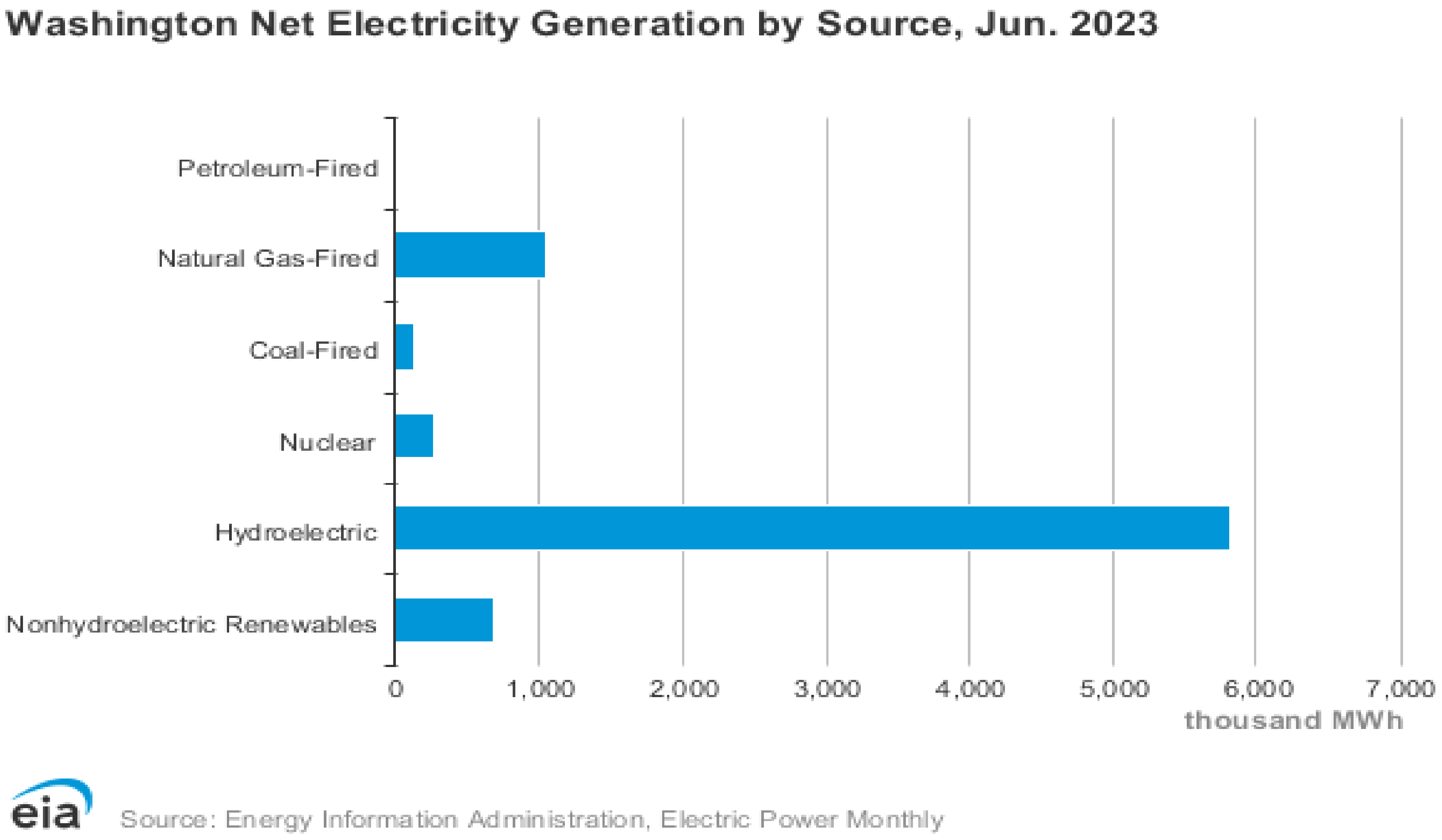


U.S. 2020 Capital costs ($/kW)



https://www.statista.com/statistics/654401/estimated-capital-cost-of-energy-generation-in-the-us-by-technology/

Most Washington electricity comes from non-fossil fuels

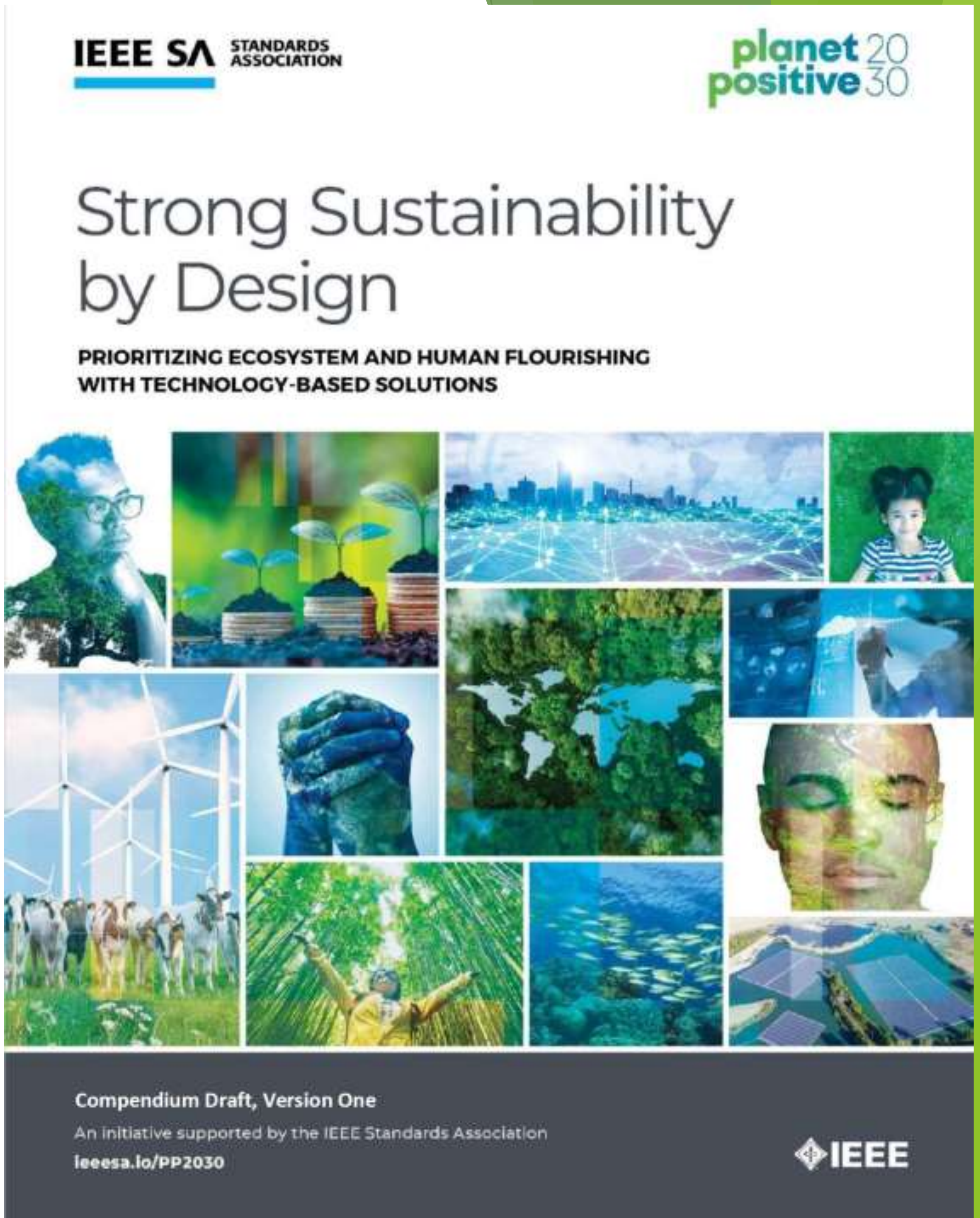


https://www.eia.gov/state/?sid=WA#tabs-4

Suggested Reading

Strong Sustainability by Design

- IEEE Standards Association has published a guide for prioritizing ecosystem and human flourishing with technology based solutions.



Electrify

- To eliminate all fossil fuel, electrify almost everything ASAP
- Total energy used would fall by half
- Americans can continue current lifestyle
- Need to produce 4x electricity
- Generators: renewables and nuclear
- Need storage and improved grid
- Long term costs would fall
- Need low-cost financing for capital costs