Sandia National Laboratories

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Opportunities for electric load growth in Alaska

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Renewable and Distributed Systems Integration

ALASKA ENERGY SECURITY TASK FORCE MEETING

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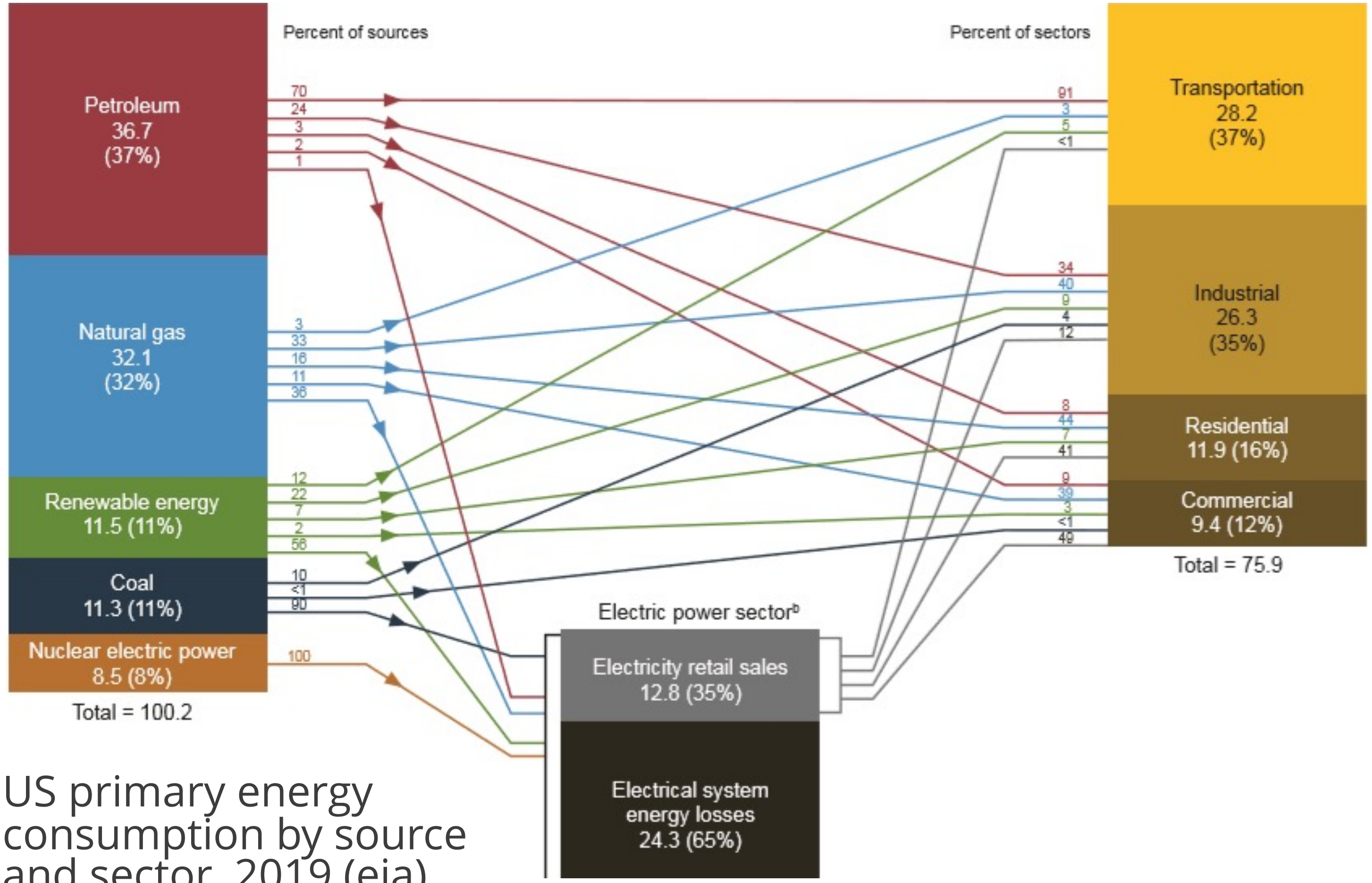
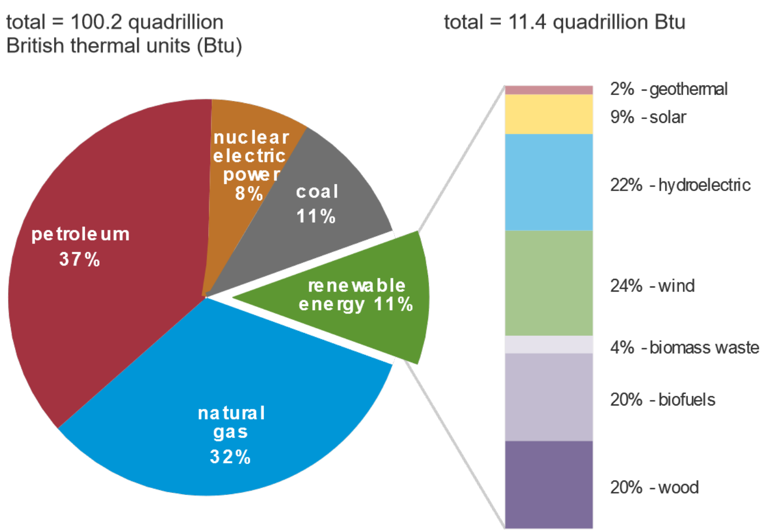
The rapidly evolving context

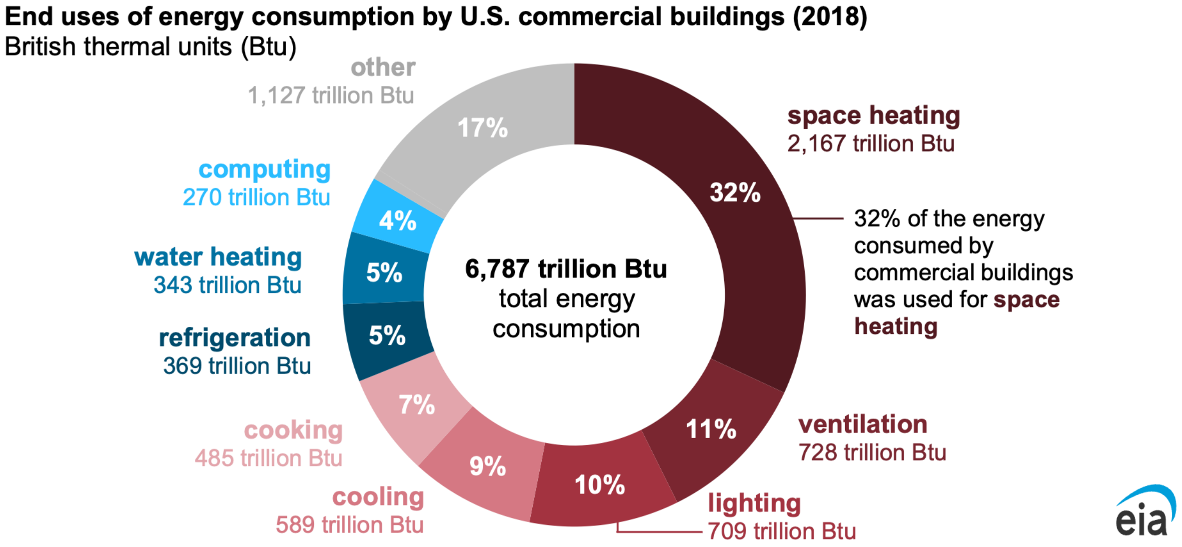


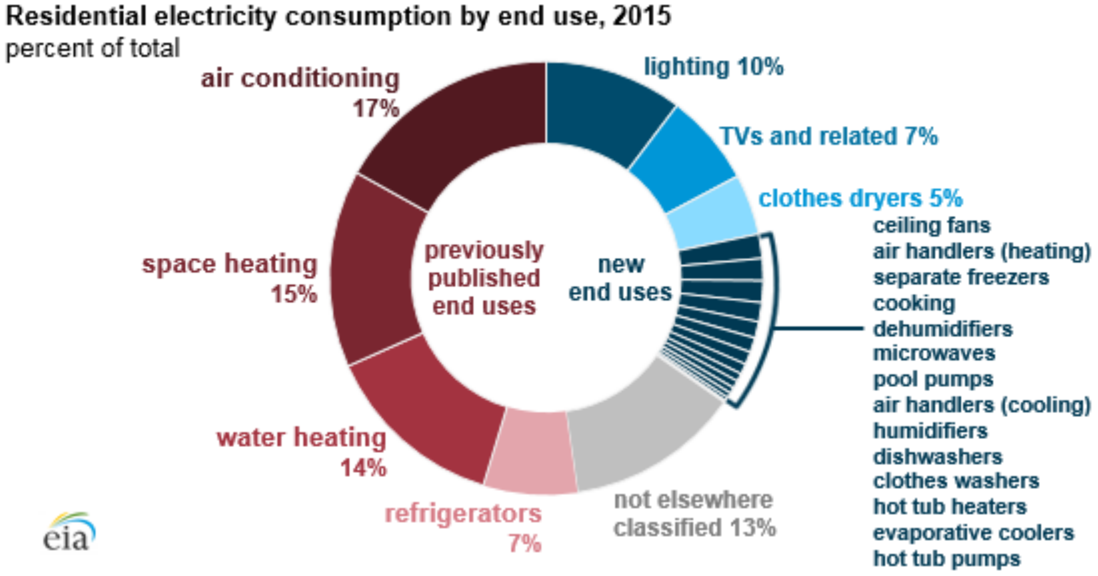
US primary energy consumption by source and sector, 2019 (eia)

US primary energy consumption by source, 2019 (eia)



What buildings do with their energy





Heating is the elephant in the conference room. CBECS has all the gory details.

Heating stuff is the elephant in the living room too. Cooling stuff is a slightly smaller elephant. RECS has the entire story.

What buildings do with their energy in Alaska

Figure 34: Total non-residential energy end-use consumption in MMBTU/yr, Climate Zones 6, 7 and 8.

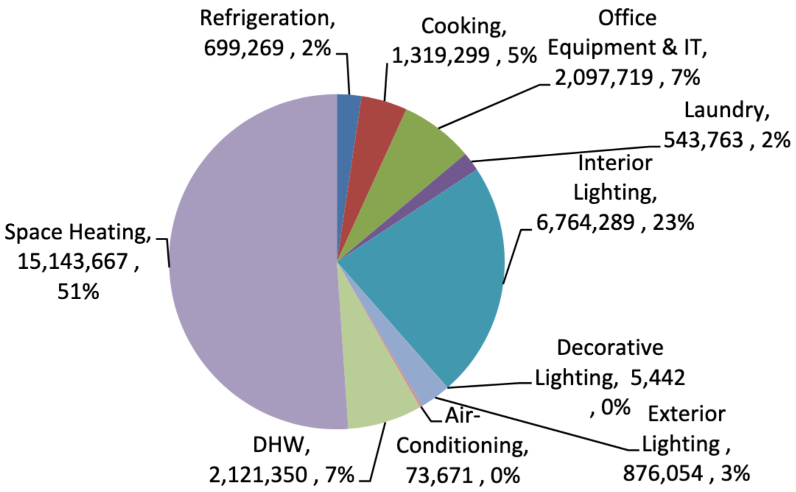
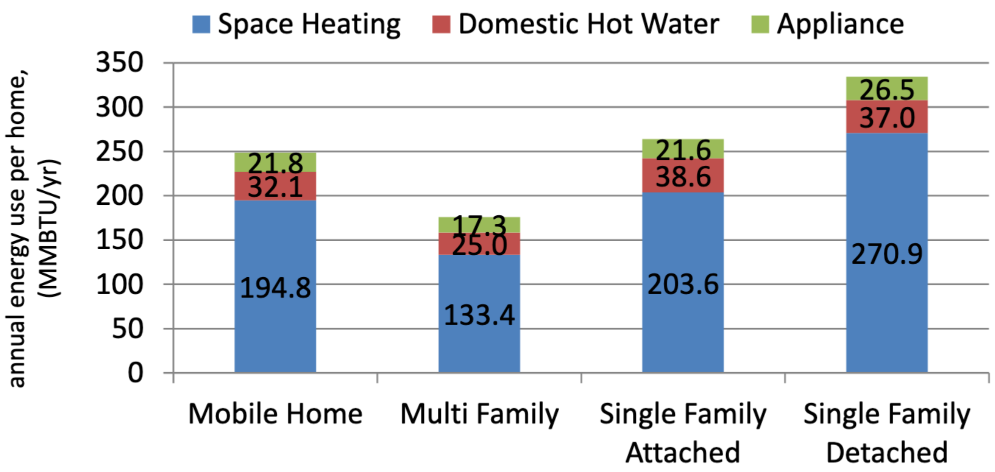


Figure 6: Total energy use per home for major energy uses by residence type (pop wt, MMBTU)

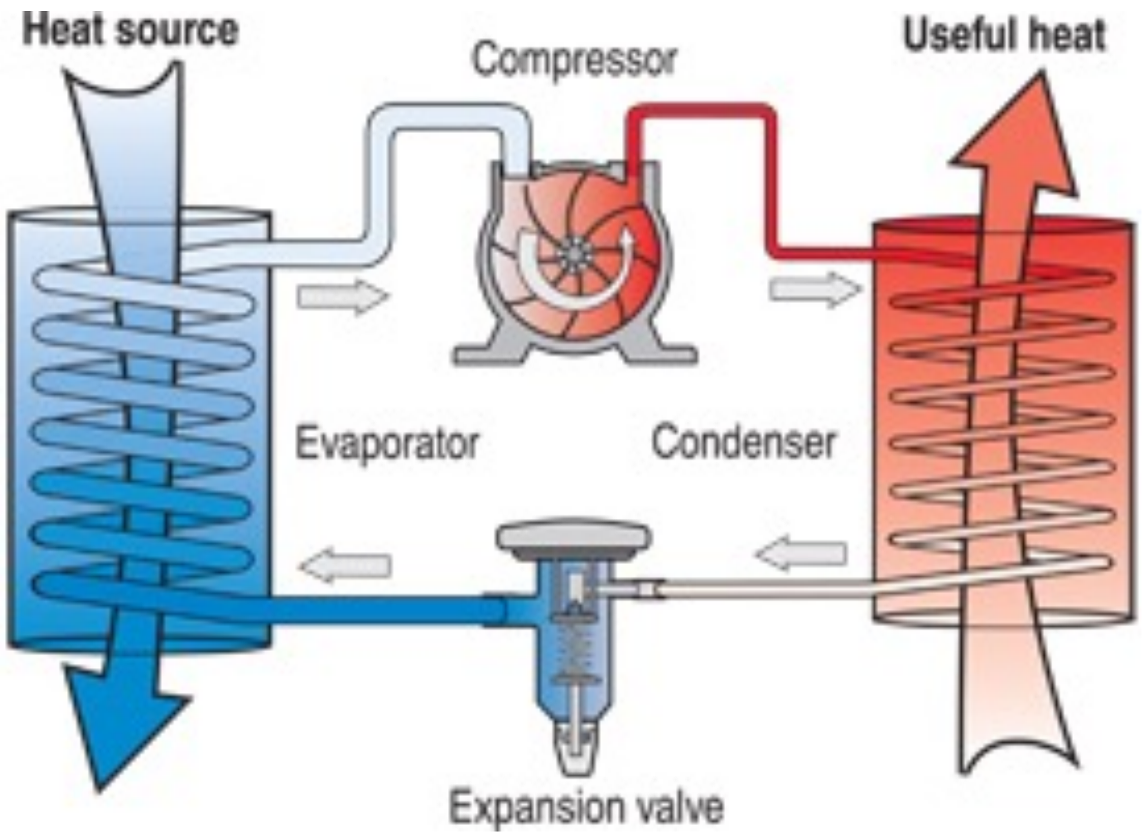


Space and water heating heating are even bigger elephants in AK conference rooms

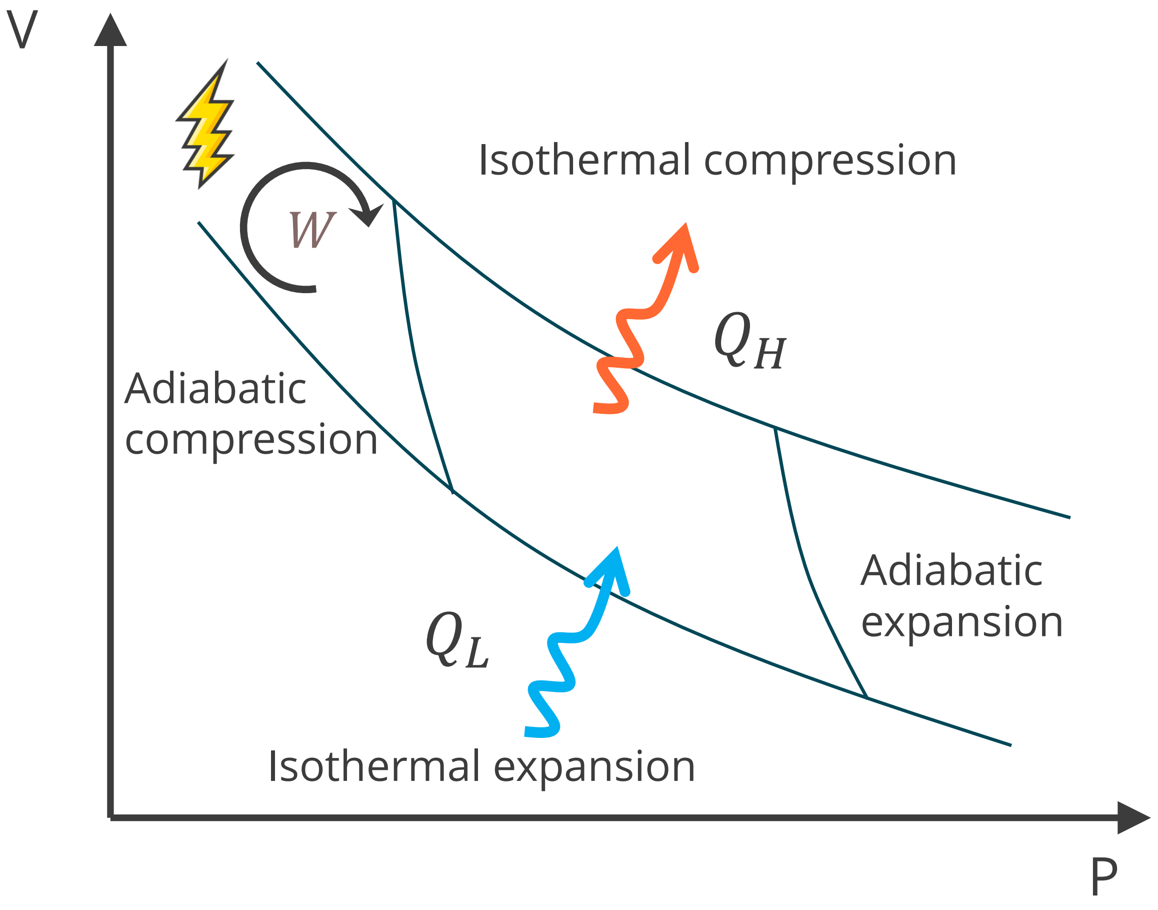
Heating space and water is *by far* the biggest Alaskan home energy user

Source: Alaska Energy Authority End Use Study: 2012

Heat pumps 101



In the weeds – the Carnot efficiency

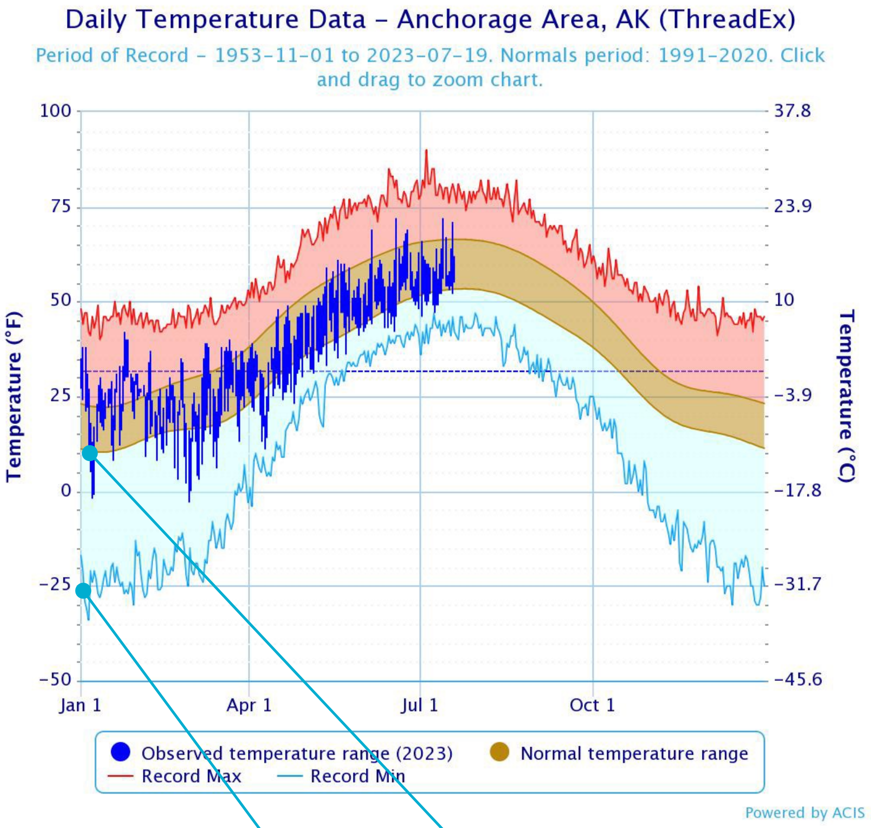


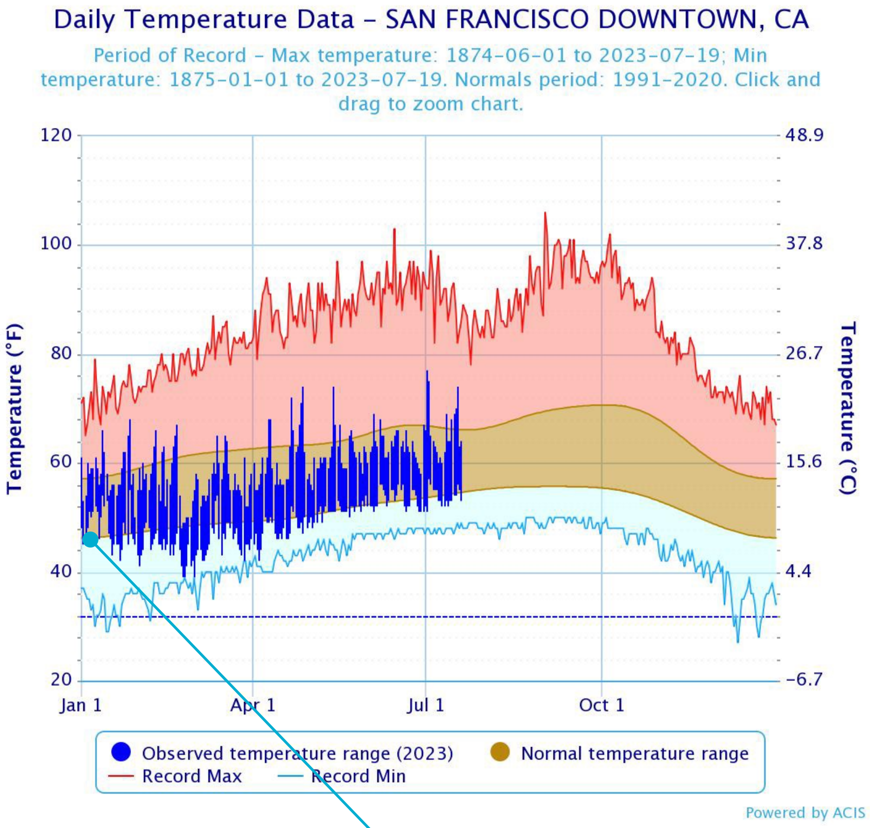
$$COP = \frac{Q_H}{W} = \frac{T_H}{T_H - T_L}$$

The COP, or Coefficient of Performance, is the ratio of amount of heat delivered to a space Q_H and the amount of work done by the compressor W, usually provided by electricity

Can heat pumps work in Alaska (at least in theory)?

NATIONAL WEATHER SERVICE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION





COP=8.97

COP=5.57

COP=22.05

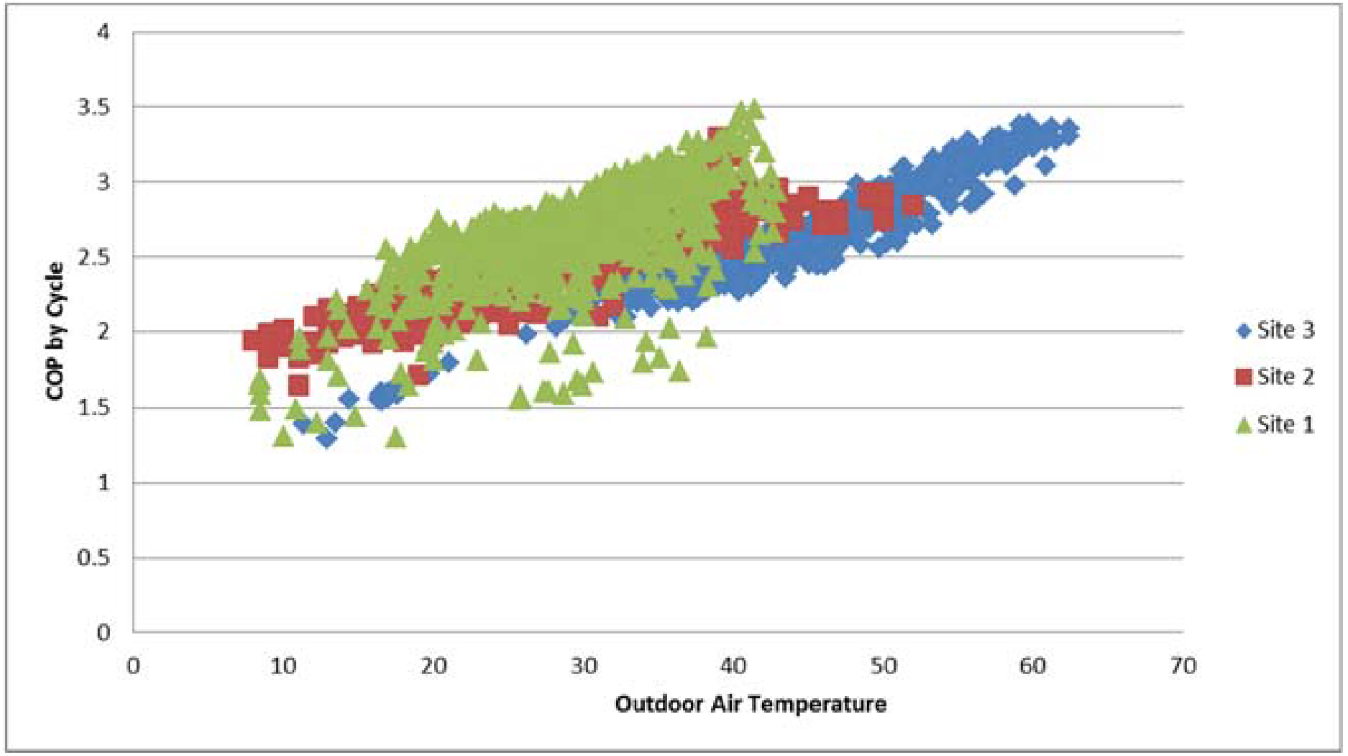
Note: these are ideal COPs!

How practical heat pumps compare to ideal ones

- A Carnot heat pump operates at equilibrium – meaning it transfers no power
- Real, practical heat pumps have much lower COP because:
  - Need temperature gradient to transfer heat, hence higher T_H and lower T_L
  - Compressor not 100% efficient
  - Motor not 100% efficient
  - Fans
  - Defrost cycles
  - Etc.

"But I heard heat pumps don't work in cold climates"

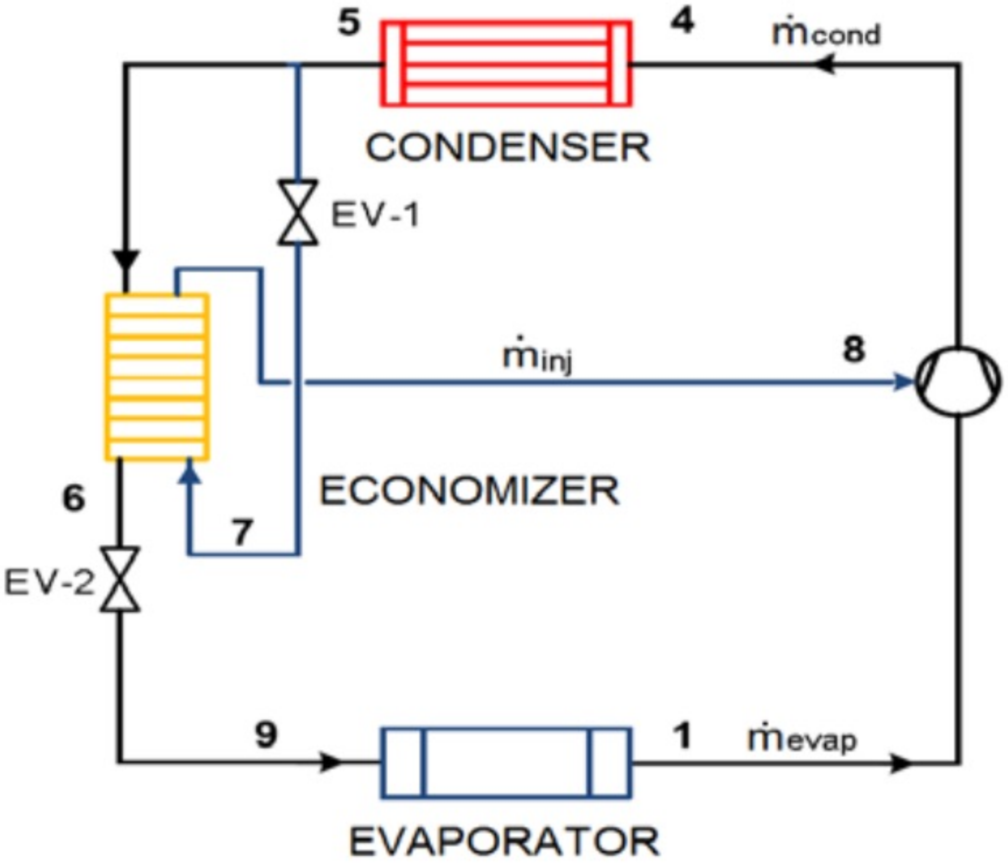
- There is some truth to this statement: the COP and capacity of a heat pump decreases as outside temperature drops
- However, recent advances have improved cold-climate performance substantially
- But are they good enough for Alaska conditions?



Schoenbauer, Ben, Nicole Kessler, David Bohac, and Marty Kushler. "Field assessment of cold climate air source heat pumps." In *ACEEE Summer Study on Energy Efficiency in Buildings*. 2016.

Recent improvements in ccASHP technology

- Cold-climate Air Source Heat Pumps take advantage of:
  - Refrigerants with lower boiling point
  - Variable speed compressor
  - Vapor injection
- Modern ccASHPs can function effectively at temperatures down to 0°F



Tello Oquendo, Fernando M., Emilio Navarro-Peris, and José Gonzálvez-Maciá. "A Methodology for Characterization of Vapor-injection Compressors." (2016). Purdue e-pubs.

How does an installer know what to select?

NEEP'S COLD CLIMATE AIR SOURCE
Heat Pump List

VIEW DETAIL

VIEW DETAIL

VIEW DETAIL

[redacted]

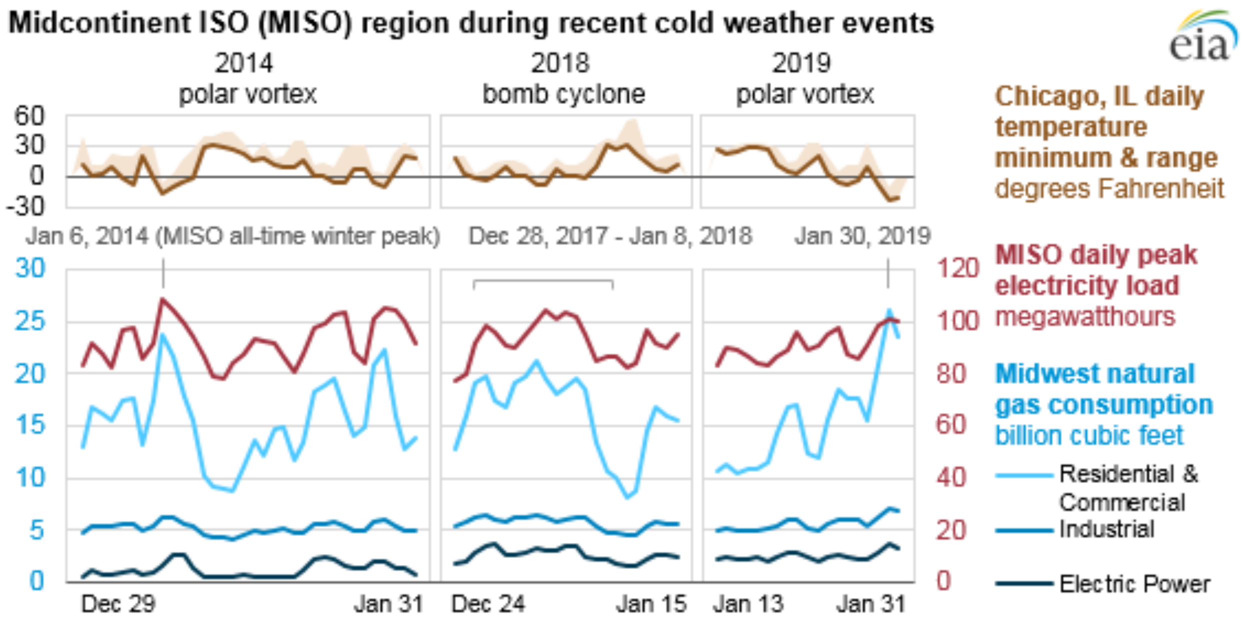
AHRI #: **201754461**
Singlezone Ducted, Compact Ducted
Central Air Conditioning Heat Pump (HP)
14,300 Max Btu/h **@5°F**
29,400 Rated Btu/h **@47°F**
24,400 Rated Btu/h **@95°F**
COP @5°F: **2.33**
HSPF: **10.8**
Outdoor Unit Model #: **PUZ-A24NHA7*****
Indoor Model #: **PEAD-A24AA***

AHRI #: **201754463**
Singlezone Ducted, Centrally Ducted
Central Air Conditioning Heat Pump (HP)
14,500 Max Btu/h **@5°F**
28,000 Rated Btu/h **@47°F**
24,000 Rated Btu/h **@95°F**
COP @5°F: **2.24**
HSPF: **9.3**
Outdoor Unit Model #: **PUZ-A24NHA7*****
Indoor Model #: **PVA-A24AA***

AHRI #: **201754460**
Singlezone Non-Ducted, Ceiling Placement
Central Air Conditioning Heat Pump (HP)
14,900 Max Btu/h **@5°F**
28,000 Rated Btu/h **@47°F**
24,000 Rated Btu/h **@95°F**
COP @5°F: **2.3**
HSPF: **10.8**
Outdoor Unit Model #: **PUZ-A24NHA7*****
Indoor Model #: **PCA-A24KA***

Potential problem with widespread HP adoption

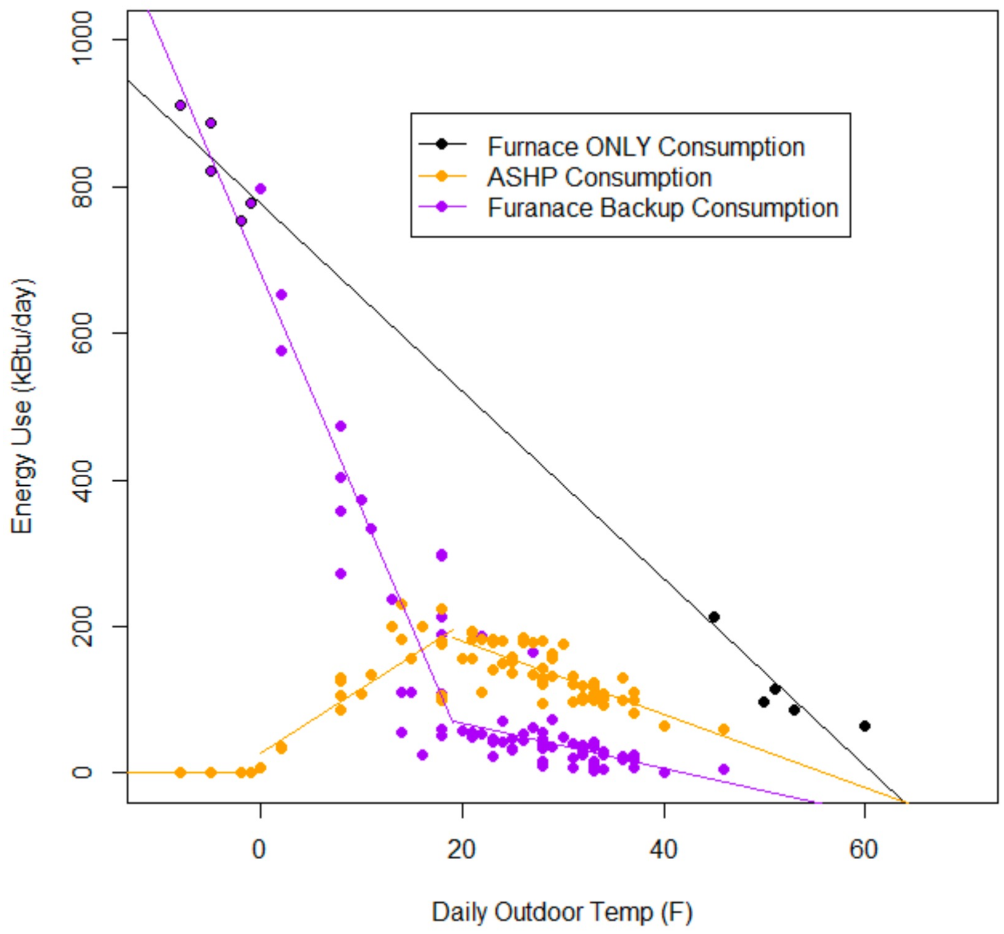
- On very cold days, ASHP may not have sufficient capacity to heat the space
- No problem, backup resistance heater comes on and provides necessary heat!
- This could place an excessive strain on the electric grid



U.S. Energy Information Administration

Solution 1: dual fuel heat pumps

- Several manufacturers offer integrated gas / ccASHP system
- Existing furnace systems can be run in parallel with new ccASHP
- The transition between gas and ccASHP operation is adjusted to suit user requirements



Schoenbauer, Ben, Nicole Kessler, David Bohac, and Marty Kushler. "Field assessment of cold climate air source heat pumps." In *ACEEE Summer Study on Energy Efficiency in Buildings*. 2016.

Solution 2: better building envelope

- Passivhaus principles:
  - Highly insulated walls
  - High-performance windows
  - Minimize thermal bridges
  - Minimize infiltration
  - heat recovery ventilation
  - Thermal storage
  - Radiant heat
- Retrofitting to passivhaus standard can be expensive
- What is a reasonable compromise?

What's wrong with this picture?

Solution 3: geothermal heat pump

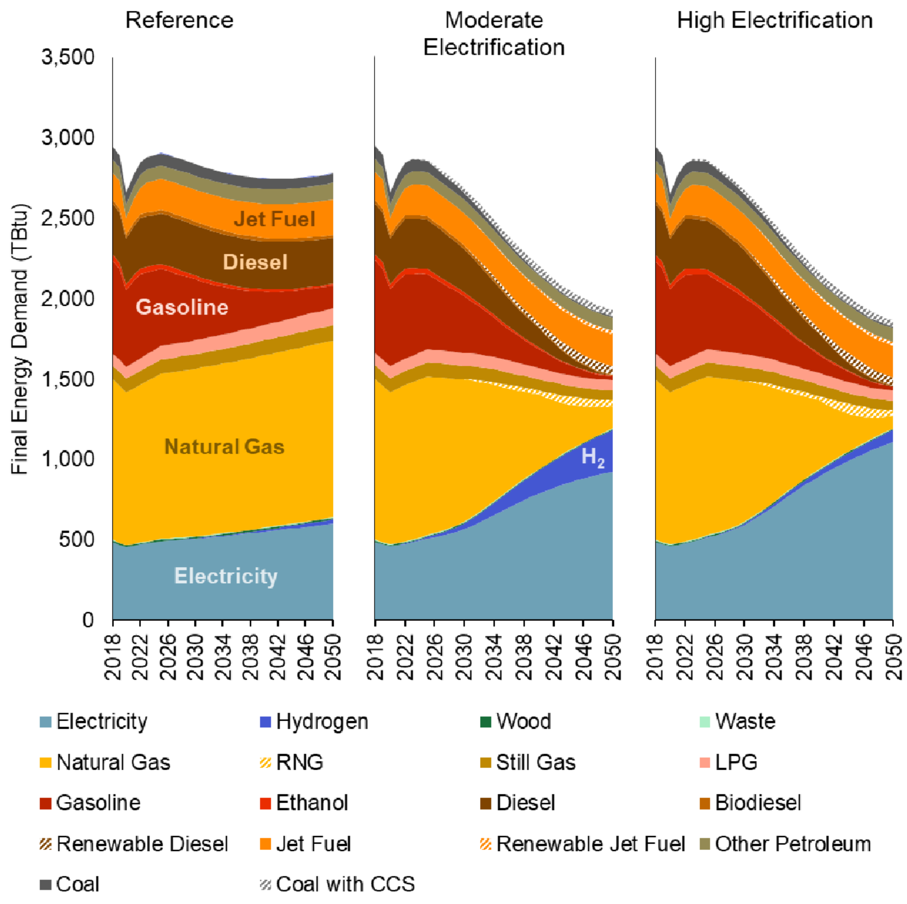
- Ground temperatures are generally constant even during cold parts of the year
- Alaska conditions are more challenging, depending on location
- Higher upfront cost are offset by energy savings in the long run
- Another option: heat exchange with ocean or other water bodies – as in the case of the Prince William Sound Science Center in Cordova, under construction now

Installation work on the ground source heat pump loop for Juneau airport, 2012

Back of the envelope calculation for heating buildings

- 1.41M metric tons of CO_2 equivalent for heating and cooking in 2020
- This corresponds to 0.512M metric tons of natural gas burned
- Assuming efficiency of 70% for a typical furnace / boiler, this corresponds to 20M GJ of heat
- Assuming an average COP of 2, this is equivalent to 2.78M MWh of electricity
- Chugach 2021 retail sales were 1.92M MWh
- Detailed study under way at ACEP

Figure 13: Final Energy Demand by Fuel in Illinois for All Scenarios



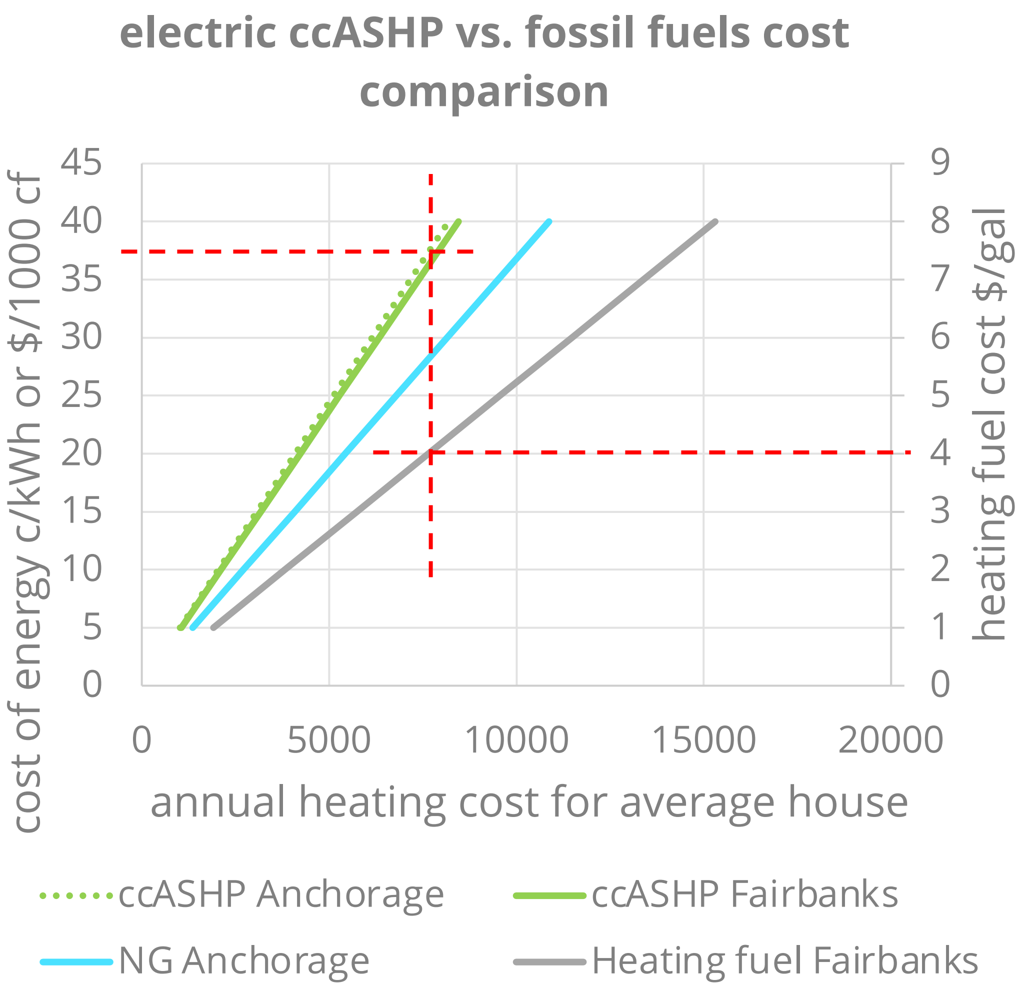
Illinois Decarbonization Study
Climate and Equitable Jobs Act and Net Zero by 2050, Energy+Environmental Economics 2022

What are the economics?

- The cost of installing a ccASHP can be from $6k to $35K in Alaska. There are rebates but these are capped and this is still a major investment
- The cost of retrofitting a house to Passivhaus standard can be 30% of the value of the house. For the “average” Anchorage house (median cost $410K in 2023), this is about $123K, not exactly pocket change, and about twice the cost of the average major remodel
- The average monthly heating cost in Alaska is $291, with a 7-month heating season
- So, does an energy retrofit make sense? What can be done to change this?

How much does it cost to run heating?

- The COP of a heat pump changes with temperature, so the cost of a unit of heat varies throughout the cooling season
- The published Heating Seasonal Performance Factor is a measure of the ”average” performance of a heat pump over a heating season and can be used to get seasonal cost
- On the other hand, NG and Heating Fuel cost per unit heat is constant



Recap so far

- Buildings use about 40% of total primary energy production in the US, but 17% in Alaska, due to large industrial energy consumption. However, 77% of all electricity sales go to commercial and residential buildings.
- Heating is the largest residential energy user in Alaska, between 76% and 83%
- Heating is also the largest commercial building energy user in Alaska, at 58% for space and water heating combined
- Most of the heat is from burning fuels, so there is an opportunity for decarbonizing heating – but how?
- Much of the decarbonization could be in the form of heat pumps
- Cold climate heat pumps have improved substantially in recent years
- The Alaska climate still poses challenges, but solutions exist
- Deep electrification of building heating could produce almost 150% electric load growth in Anchorage

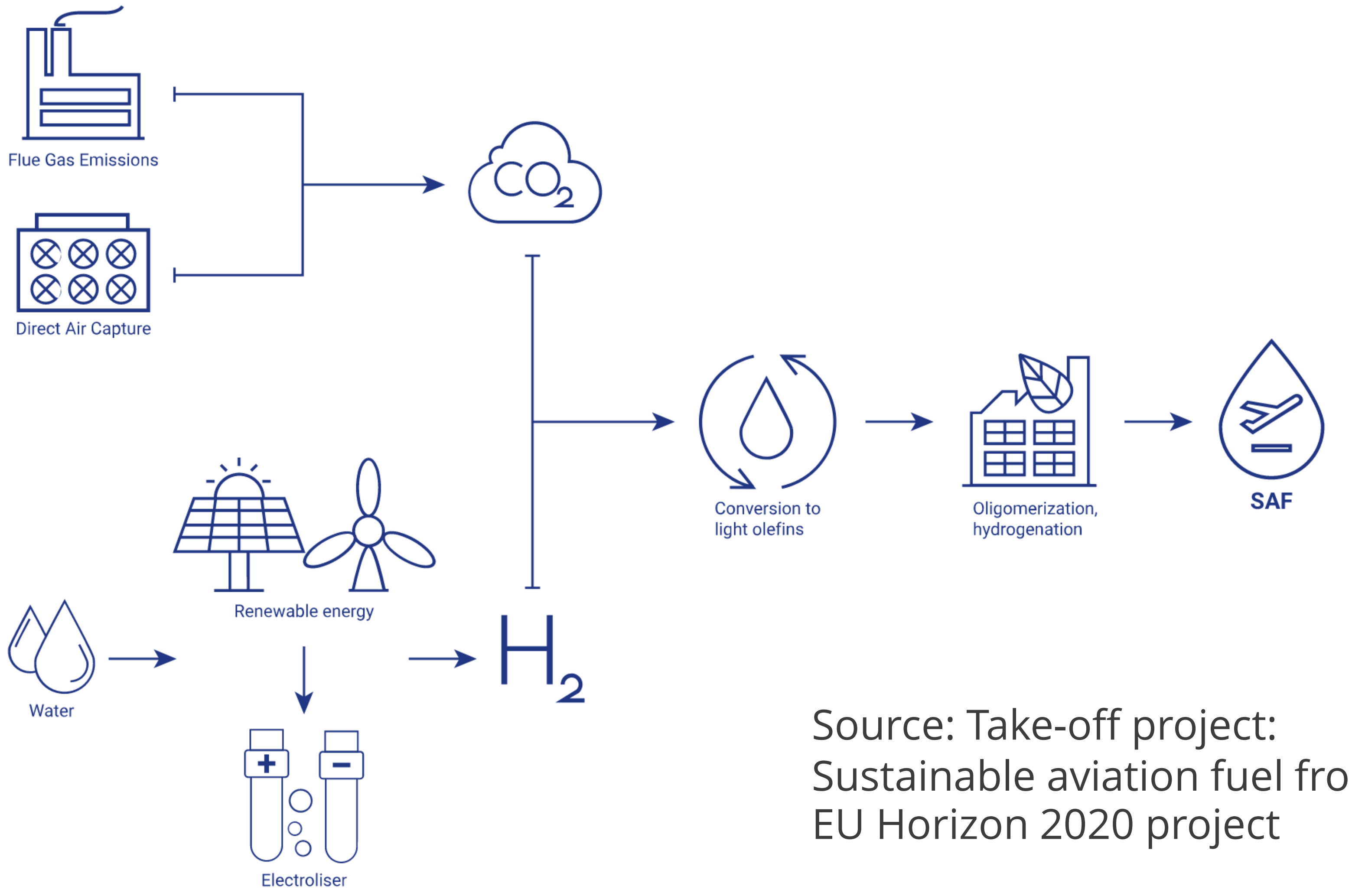
Electrification of the chemicals industry

- The chemicals industry is responsible for 37% of all industrial emissions in the US (EPA 2021)
- Petrochemicals are organic chemicals made primarily using oil, gas and coal
- Petrochemicals are used in a wide variety of consumer products ranging from pharmaceuticals to shampoo to plastic bottles
- There is vast potential to shift the source of carbon from fossil to CO_2 contained in flue gases or even the atmosphere

Sustainable aviation fuel

- Aviation is developing drop-in solutions for existing fleet and infrastructure
- Feedstocks:
  - Waste oil / fats
  - Municipal waste
  - Non-food biomass
  - Synthetic route via DAC and H_2
- SAF is carbon neutral because carbon released in combustion is derived from carbon absorbed from atmosphere
- But – currently only 0.1% of total fuel used in aviation industry is SAF (IEA)
- ANC uses almost 2M gal of jet fuel per day!

One route to production at scale



Source: Take-off project:
Sustainable aviation fuel from CO2.
EU Horizon 2020 project

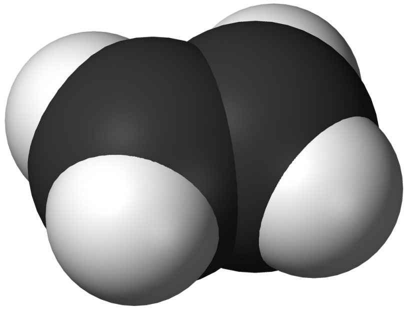
How far are we from chemicals by electrolysis?

- 175 million tons of ethylene are produced per year* (this is one of the highest production chemicals)
- All the renewable energy produced in 2022 (8,500TWh) would not be enough to electrify ethylene production alone (energy need estimated at ~12,000TWh*)
- Is this good news or bad news?

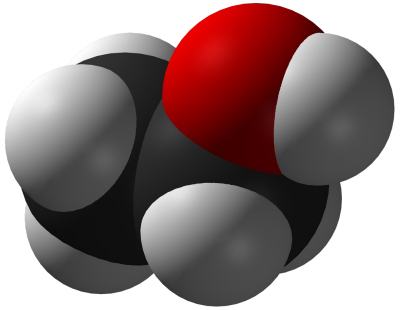
* Source: Xia, Rong, Sean Overa, and Feng Jiao. "Emerging electrochemical processes to decarbonize the chemical industry." *JACS Au* 2, no. 5 (2022): 1054-1070.

Emerging trends

- Electrification of the production of high-carbon-footprint commodity chemicals such as ammonia, nitric acid, ethylene, urea is key to meeting emissions goals
- Production of commodity chemicals by electrolysis to date has not been adopted due to high cost of electricity and lack of technology to allow production at scale
- The cost of renewable electricity, particularly solar PV, continues to drop, from an average of 5c/kWh today to a target of 2c/kWh in 2030 (DOE)
- Rapid progress is being made on suitable catalysts / reactors
- The global petrochemicals market is projected to grow from $582.4 billion in 2021 to $888.3 billion in 2028 (Fortune Business Insights 2022)
- Ammonia and other nitrogen compounds hold similar potential



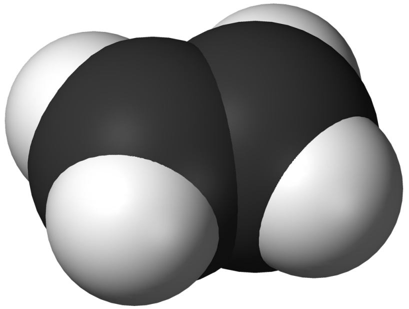
Ethylene molecule



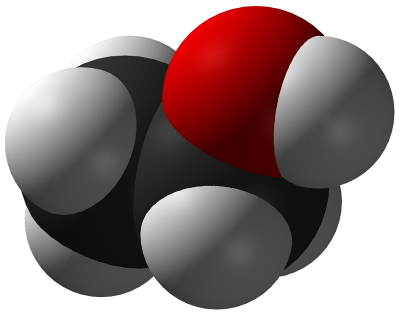
Ethanol molecule

Opportunities for Alaska

- Massive increase in solar, wind, hydro (and nuclear?) generation needed to meet decarbonization targets
- There is potential for large curtailment of solar or wind during certain parts of the year
- Curtailed energy can be absorbed by synthetic fuels or chemicals manufacturing
- Modular, non-steady-state production routes are also being investigated by many
- Hydro power can also play a major role
- Fills a need for aviation and maritime transportation
- TEA needed to establish economic viability of a new type of seasonal industry



Ethylene molecule



Ethanol molecule

Questions?