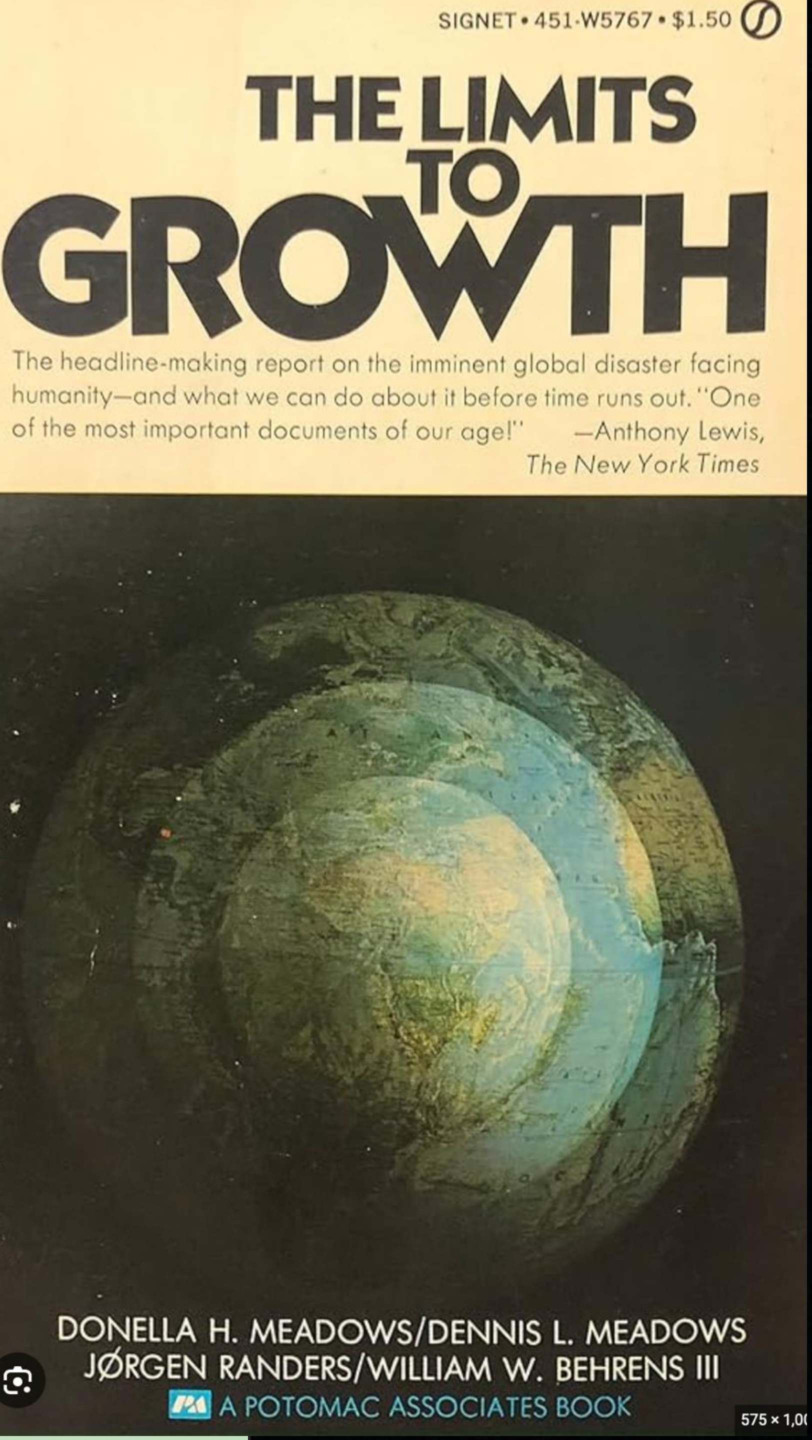
THE PATH TO ZERO

Industrial output per capita

STAENGL ENGINEERING

Passive to POSITIVE

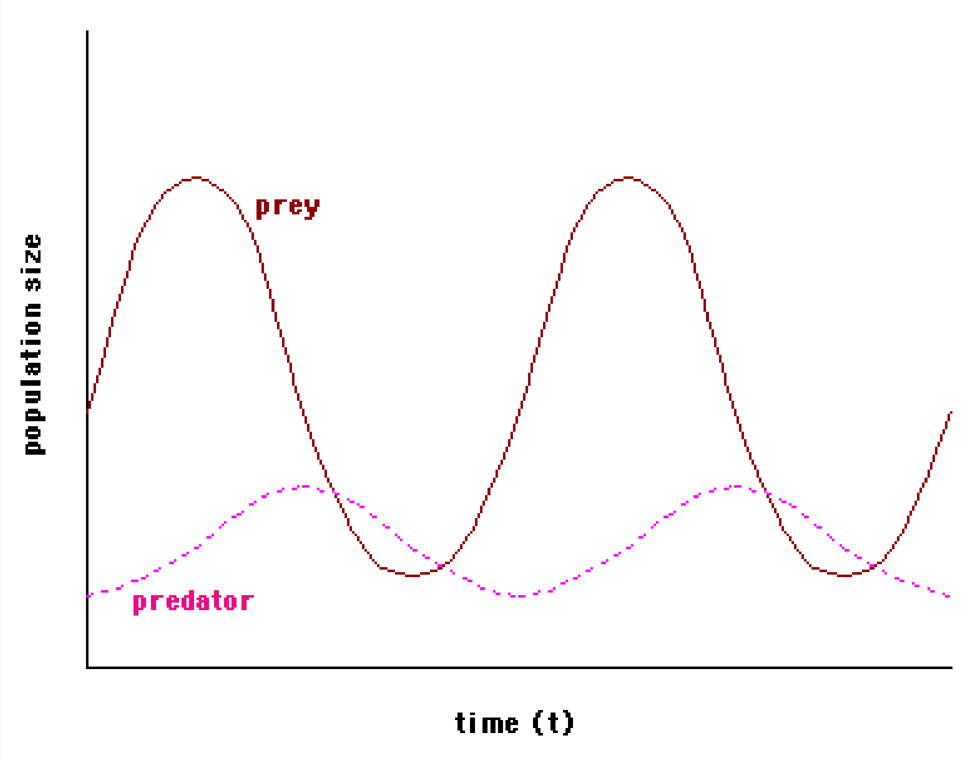
PASSIVE HOUSE AND LOW IMPACT DESIGN

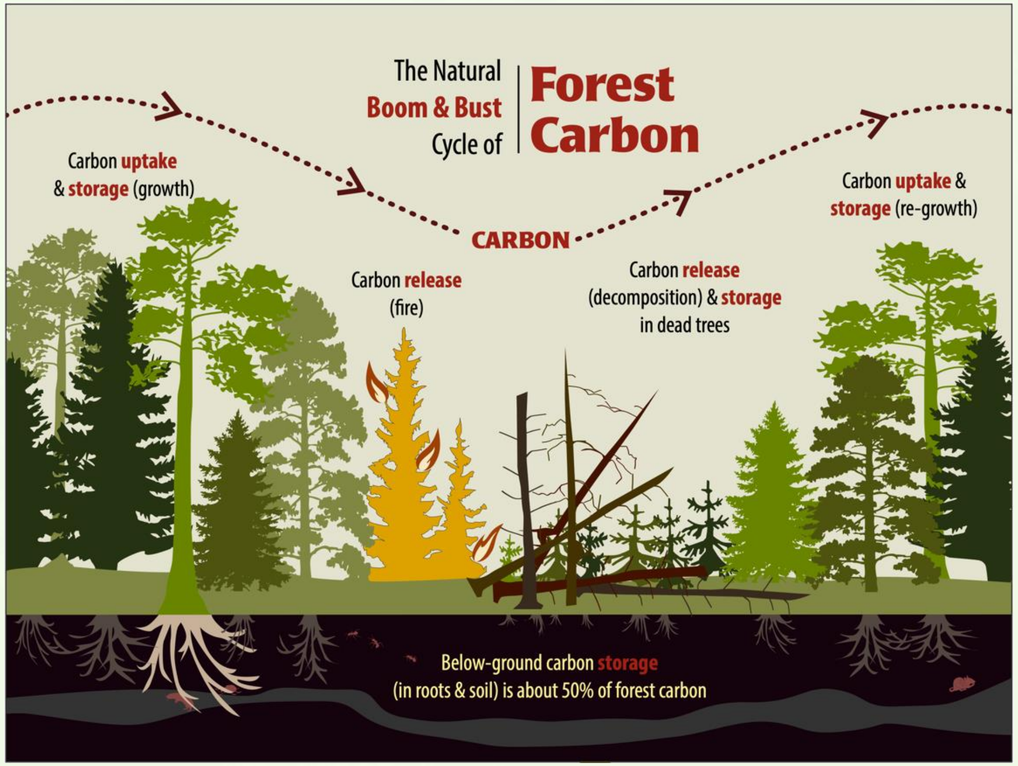


WHAT DOES **ZERO** EVEN MEAN ANYMORE ?

NATURAL SYSTEMS

FUNCTION WITHIN RESOURCE LIMITS – NO WASTE





THE CAPACITY FOR REGENERATION

Recent Past, 1961 - 1979

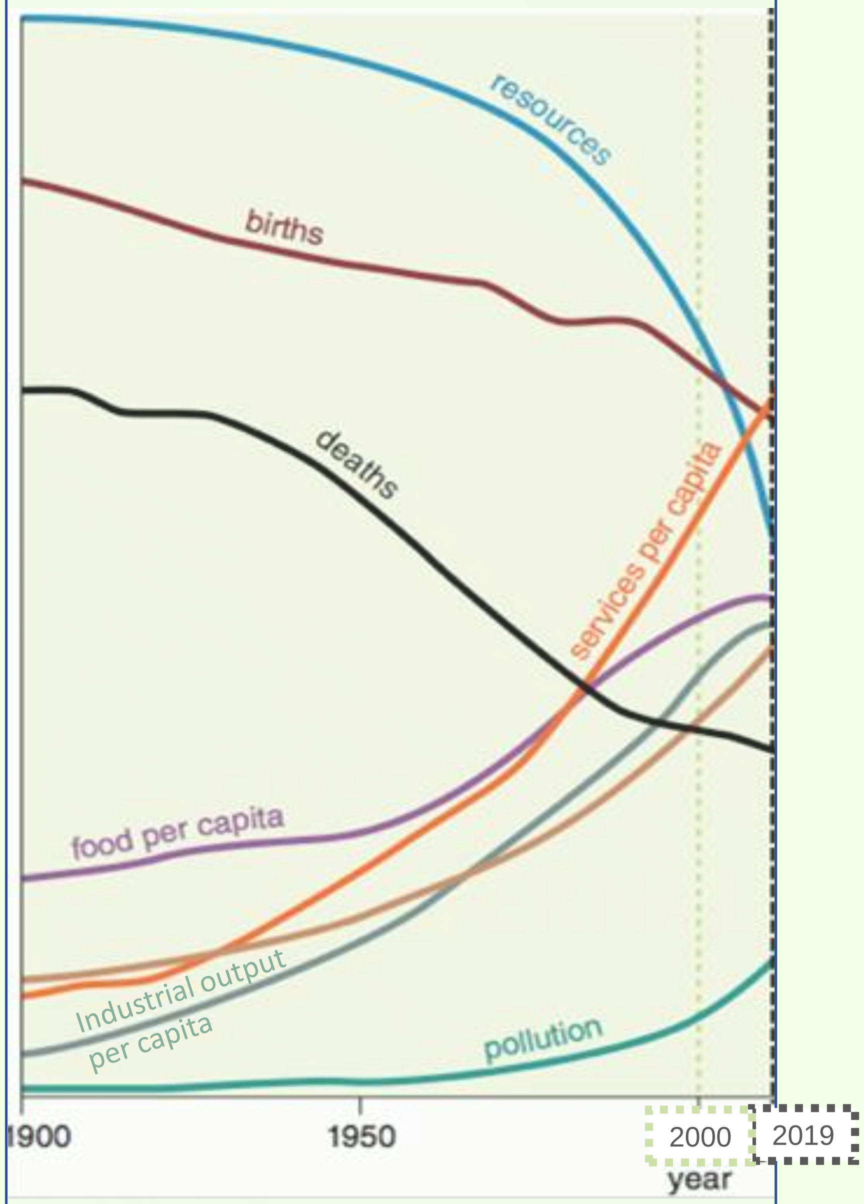
CLASSIC OSCILLATION - DYNAMIC EQUILIBRIUM

HUMAN SYSTEMS

Image credit Wall Street Journal

THE PREVAILING PARADIGM OF GROWTH

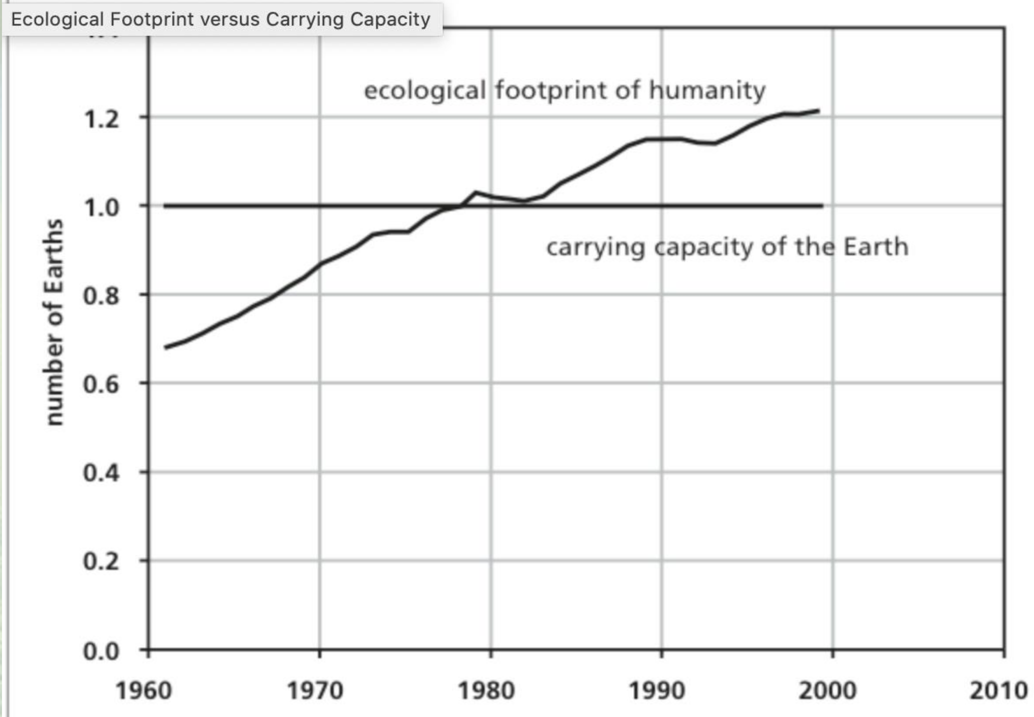
THE VIEW FROM MY LIFETIME



PERPETUAL **GROWTH**

WHAT'S NOT TO **LOVE?**

WE NEED THREE **PLANETS**

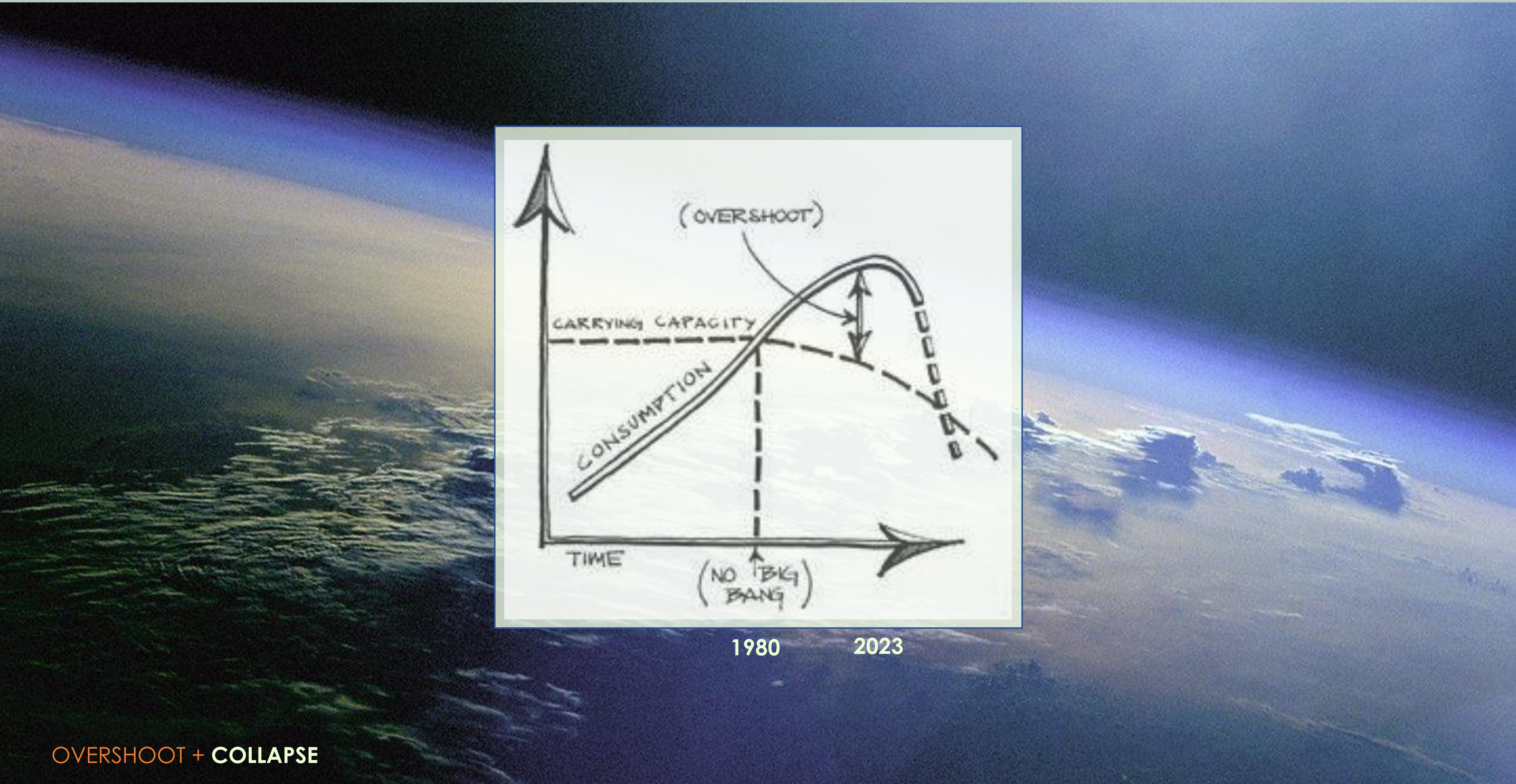


Ecological Footprint versus Carrying Capacity

This graph shows the number of Earths required to provide the resources used by humanity and to absorb their emissions for each year since 1960. This human demand is compared with the available supply: our one planet Earth. Human demand exceeds nature's supply from the 1980s onward, over-shooting it by some 20 percent in 1999. (Source: M. Wackernagel et al.)

Limits to Growth; the 30 Year Update

WE NEED THREE **PLANETS**



OVERSHOOT + **COLLAPSE**

OVERSHOOT IS REALITY : WHAT IS OUR FUTURE?

FOUR CONCEIVABLE OUTCOMES

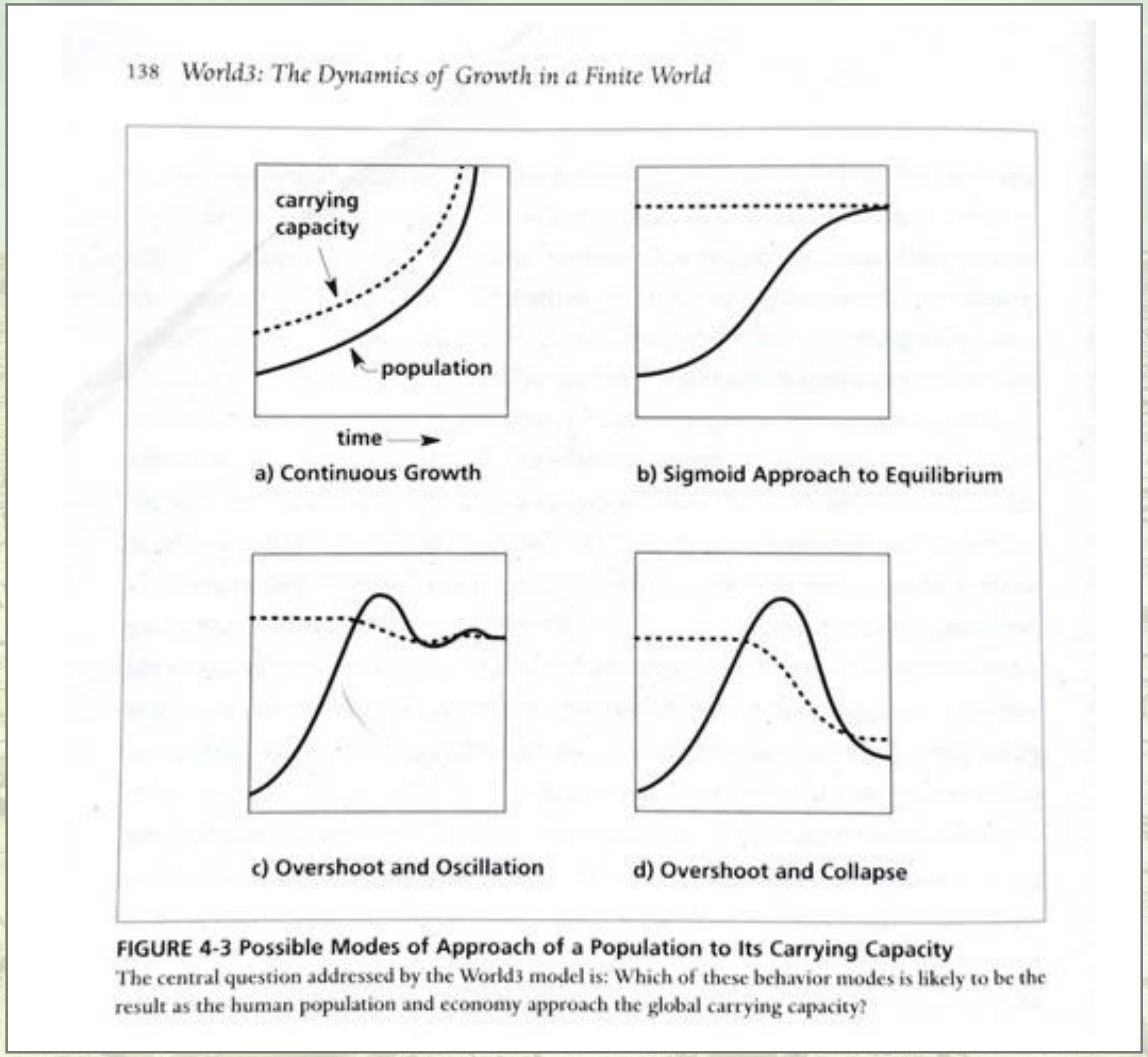

138 *World3: The Dynamics of Growth in a Finite World*

FIGURE 4-3 Possible Modes of Approach of a Population to Its Carrying Capacity
The central question addressed by the World3 model is: Which of these behavior modes is likely to be the result as the human population and economy approach the global carrying capacity?

a) Pure fantasy

b) Too late

c) The *ONLY* available path

d) Our current trajectory

NON-RENEWABLE RESOURCES

GONE FOREVER


RENEWABLE RESOURCES
ALL HAVE REGENERATION RATES
WATER – ATMOSPHERE – SOLAR – WIND – THE BIOSPHERE
We have surpassed renewable capacity but could come back down under sustainable limits
OVERSHOOT

RENEWABLE RESOURCES

ALL HAVE REGENERATION RATES - SOME ARE ERODABLE

EROSION OF REGENERATIVE CAPACITY

Fossil Fuels

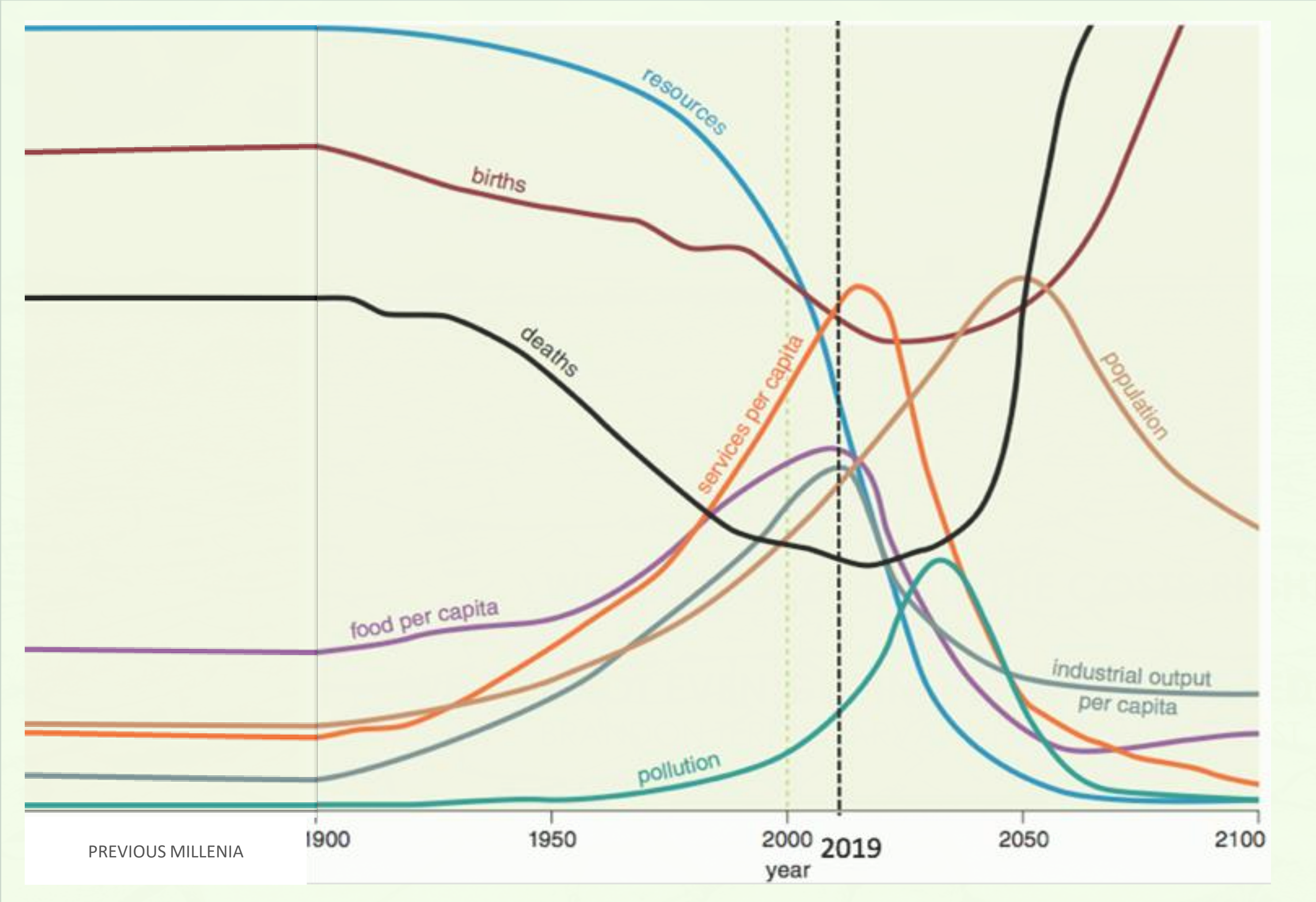
Pennsylvania's Gas Industry Used 160 Million Pounds of Secret Chemicals From 2012 to 2022, a New Report Says

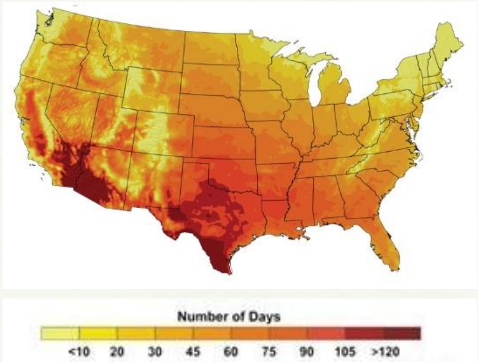
Researchers say unidentified additives may have included "forever chemicals" linked to serious health problems.

By Jon Hurdle
October 24, 2023

MAY BE GONE FOREVER (FOR HUMAN TIMESCALE)

THE CURENT TRAJECTORY





temperature map images: U.S. Global Change Research Program

WILL TECHNOLOGY AND EFFICIENCY SAVE US?

MORE RESOURCES AND GREATER EFFICIENCY

FANTASY – NO LIMITS

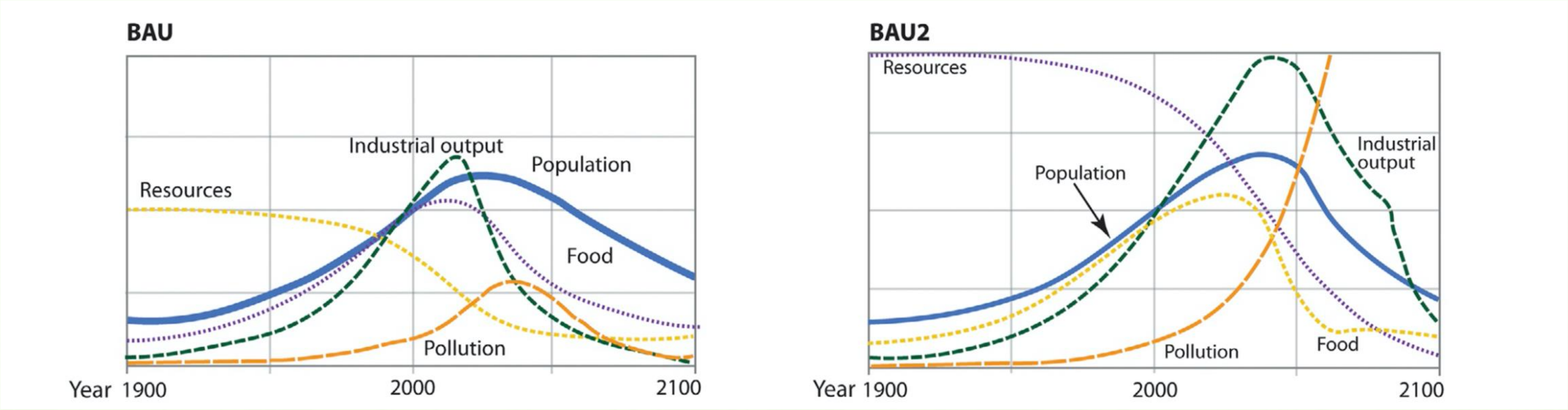
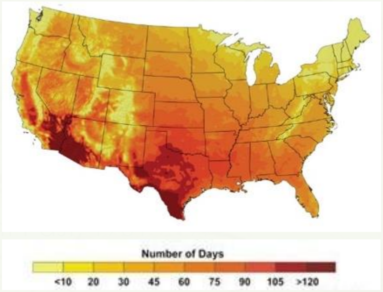


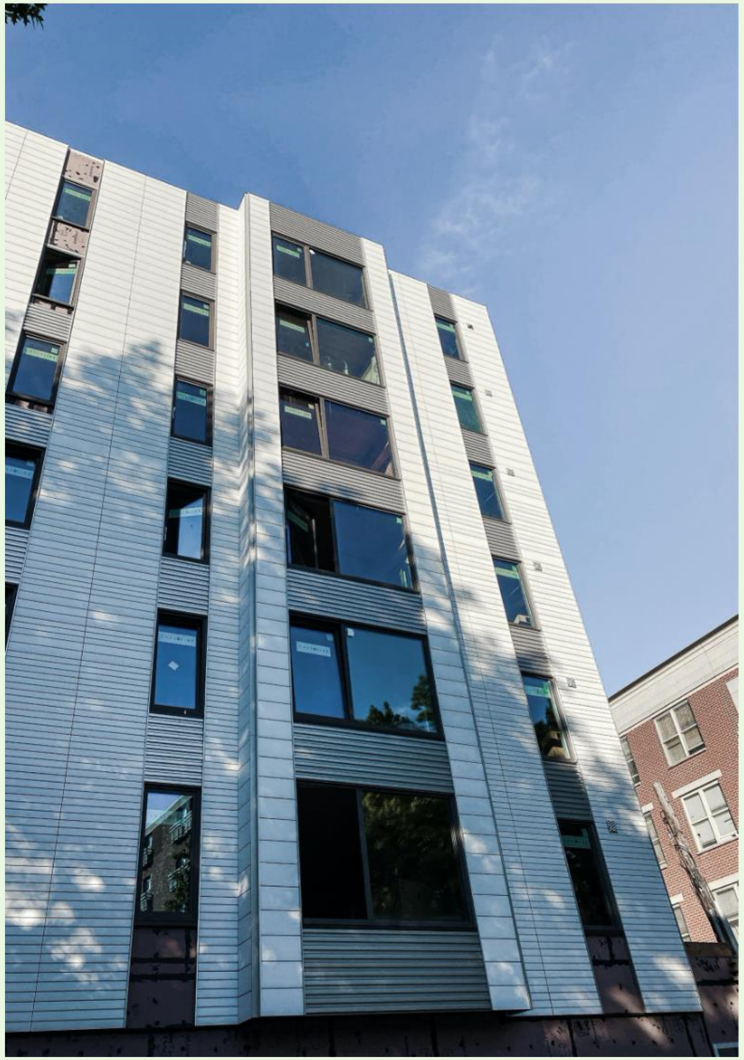
FIGURE 1 The BAU, BAU2, CT, and SW scenarios. Adapted from *Limits to Growth: The 30-Year Update* (p. 169, 173, 219, 245), by Meadows, D. H., Meadows, D. L., and Randers, J., 2004. Chelsea Green Publishing Co. Copyright 2004 by Dennis Meadows. Adapted with permission

EVEN WITH:

- 200% LAND YIELD INCREASE
- NO LAND ENCROACHMENT DESPITE HUGE POPULATION
- PERPETUAL 4% REDUCTION IN EMISSIONS
- TOTAL RECYCLING
- ACCELERATED TECHNOLOGICAL IMPROVEMENTS



temperature map images: U.S. Global Change Research Program



The Path to Zero Carbon?: CASE STUDY

CLT, Passive House and Low Refrigerant

BUILDING SYSTEMS – STRUCTURE

MASS TIMBER STRUCTURE (BY NORDIC)

- GLULAM MASS TIMBER POSTS AND BEAMS
- CROSS LAMINATED TIMBER SLABS

Volume of wood products used:
950 cubic meters (33,549 cubic feet)

U.S. and Canadian forests grow this much wood in:
3 minutes

Carbon stored in the wood:
844 metric tons of carbon dioxide

Avoided greenhouse gas emissions:
327 metric tons of carbon dioxide

Total potential carbon benefit:
1171 metric tons of carbon dioxide

PREFABRICATED MODULAR STEEL VERTICAL CORES WITH CIP

7 STEEL TRANSFER MEMBERS AT GRADE

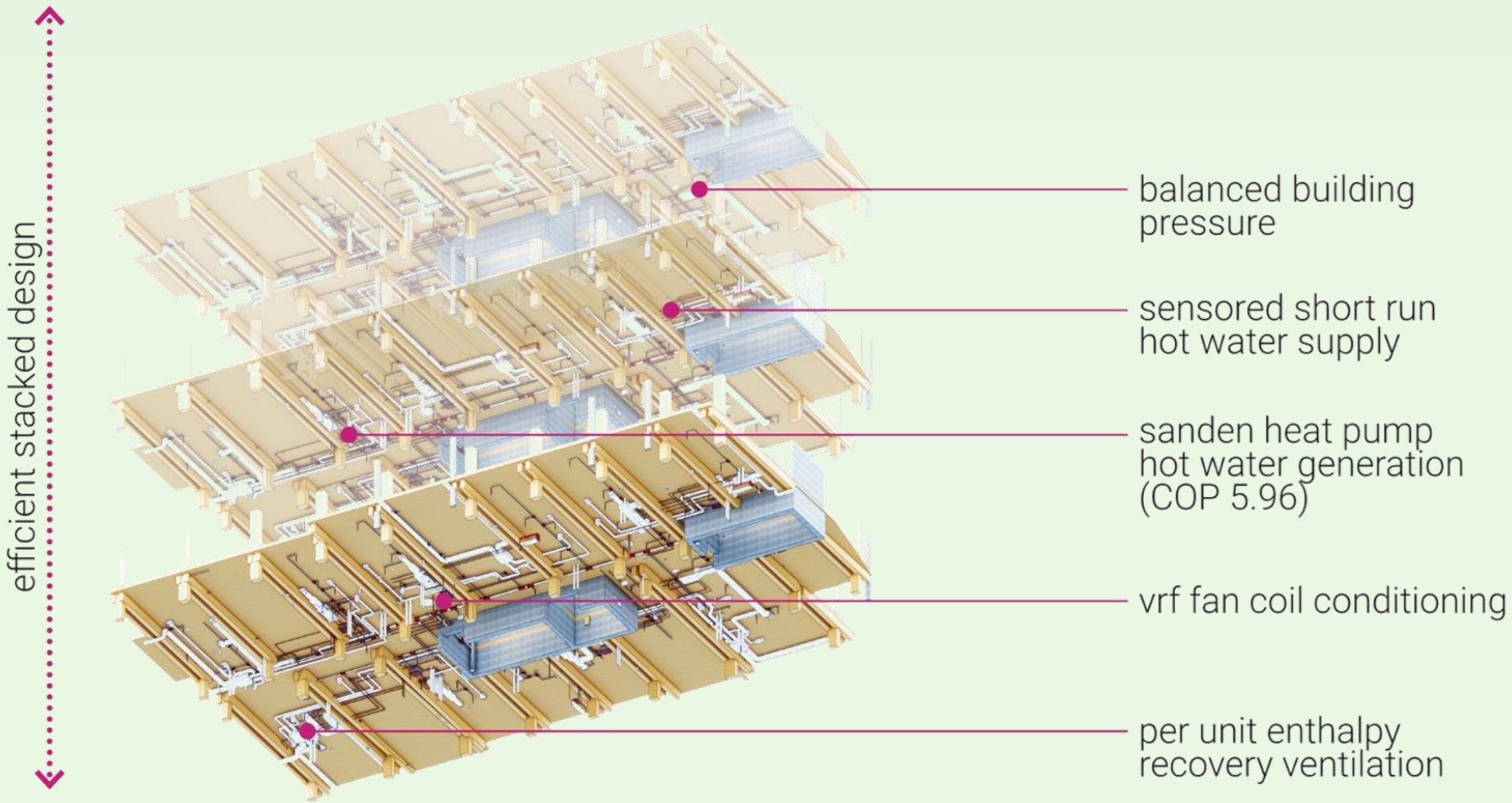
SHALLOW FOUNDATION SYSTEM WITH RAMMED AGGREGATE PIERS

FRESH AIR: PER UNIT DECENTRALIZED PANASONIC ERVS

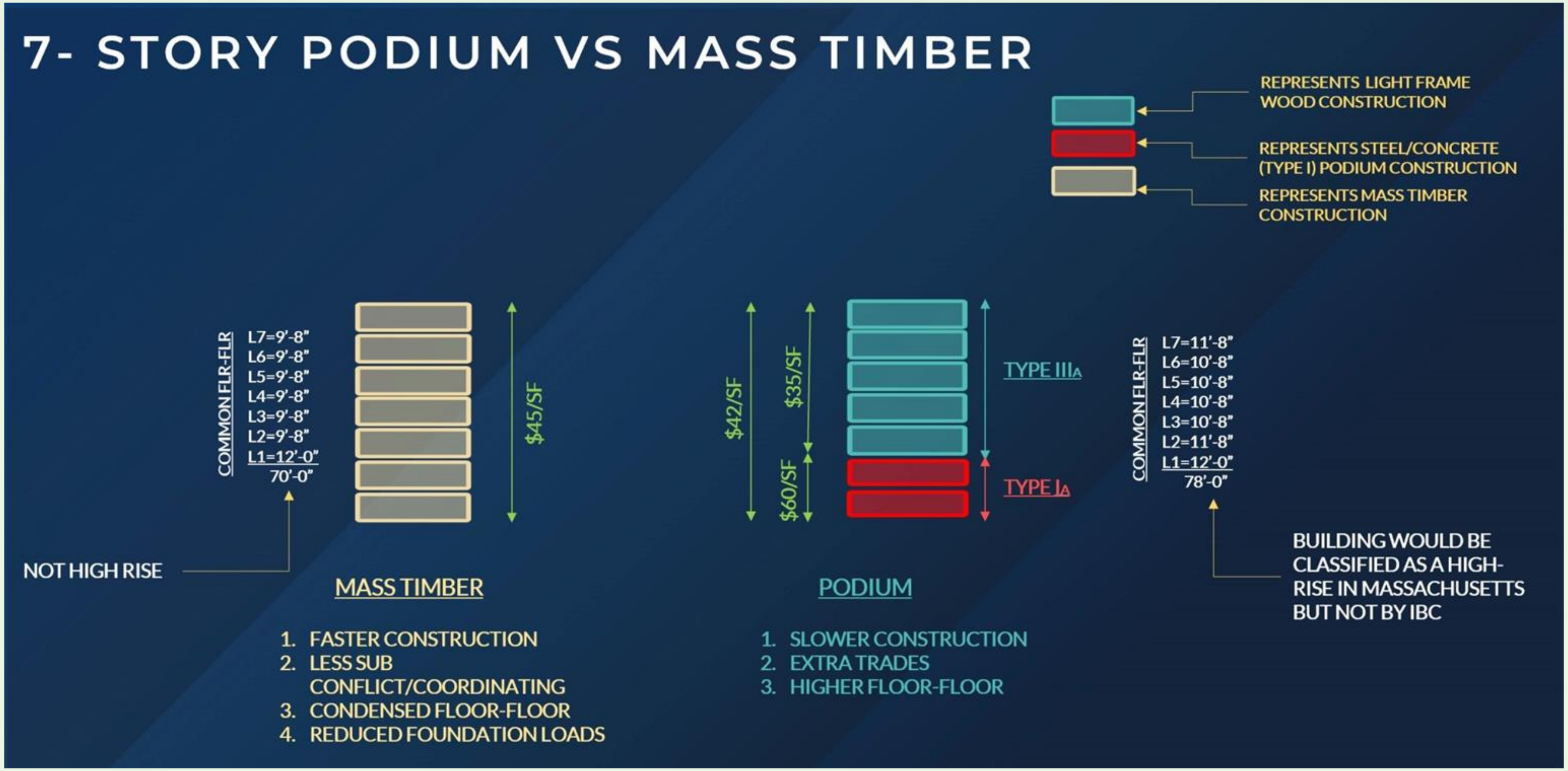
HEATING / COOLING: CENTRALIZED DAIKIN VRF SYSTEM WITH WALL MOUNT DUCTLESS AND CEILING MOUNT DUCTED UNITS

HOT WATER: SANCO2 HEAT PUMP

PV GENERATION: 40,000 KWH/YR



MASS TIMBER AND PASSIVE HOUSE **SYNERGISTIC BENEFITS**

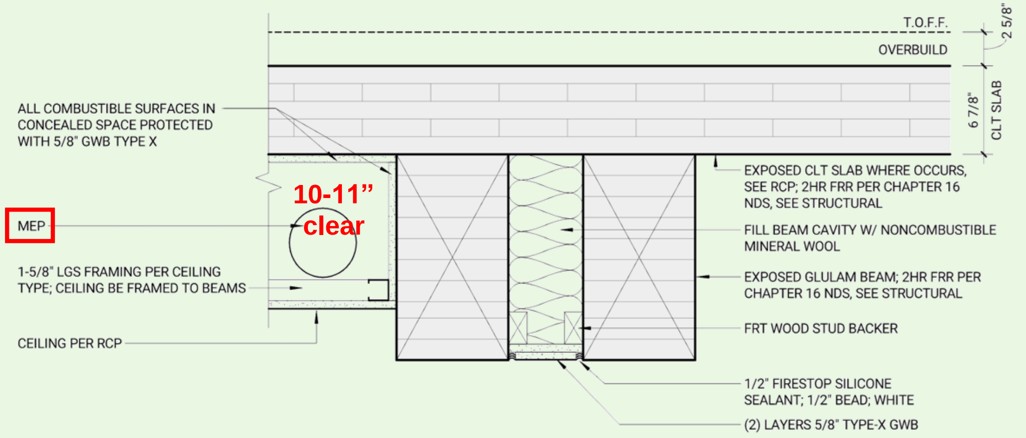


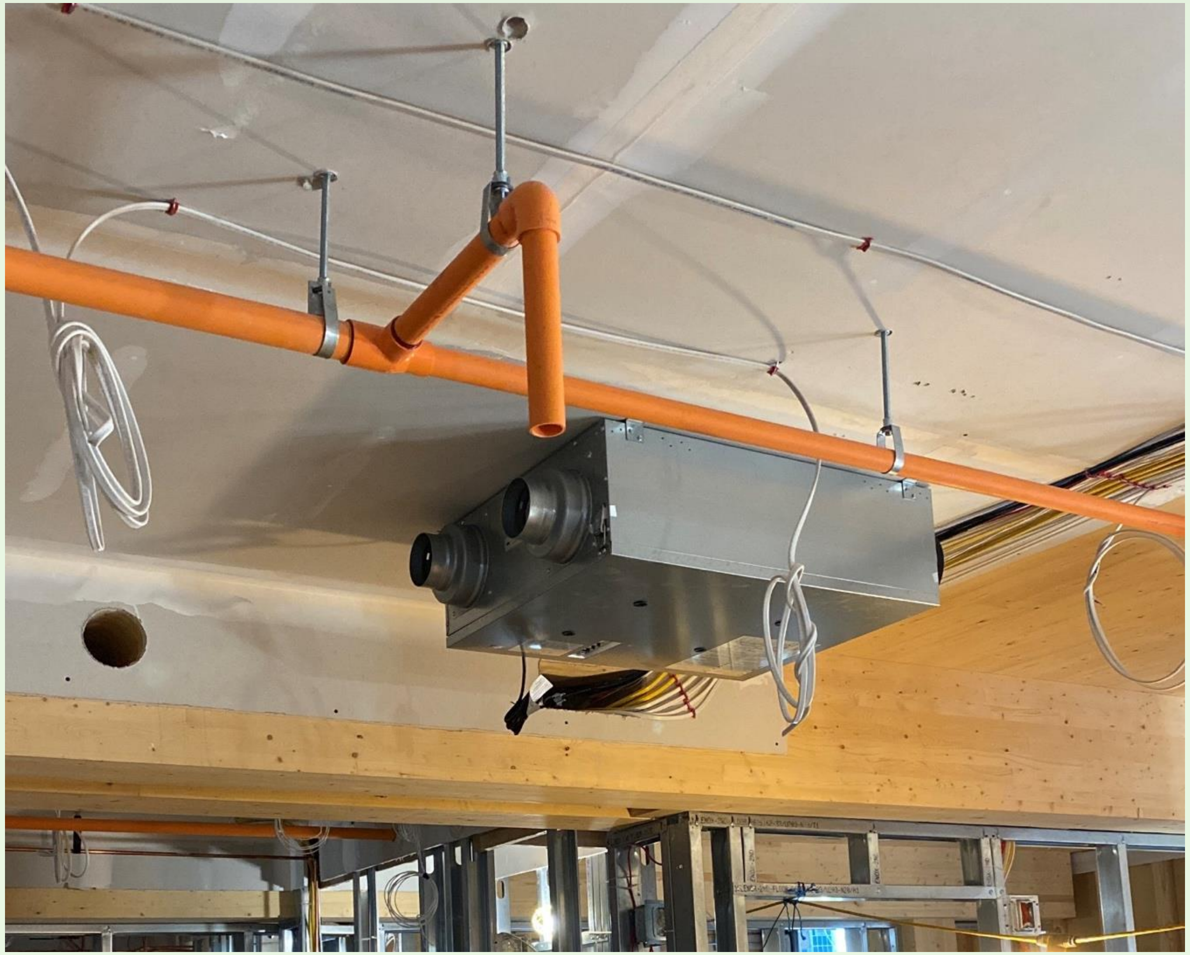
- SPACE IS A BIGGER COST PREMIUM THAN TIMBER STRUCTURAL SYSTEMS
- SPACE IS A BIGGER COST PREMIUM THAN MEP SYSTEMS
- MINIMAL RIGHT SIZE SYSTEM
- MINIMAL PLENUMS AND CHASES
- MINIMIZED STRUCTURAL PENETRATIONS

MASS TIMBER AND PASSIVE HOUSE **SYNERGISTIC BENEFITS**

MINIMAL PLENUMS

- 11 E LENOX < 70FT TALL
- 9’-8” FLOOR-TO-FLOOR
- MASS TIMBER STRUCTURALLY ALLOWS FOR 7 UNDER 70
- PHIUS DESIGN MINIMIZED PLENUM DEPTHS TO 10” - 11” CLEAR



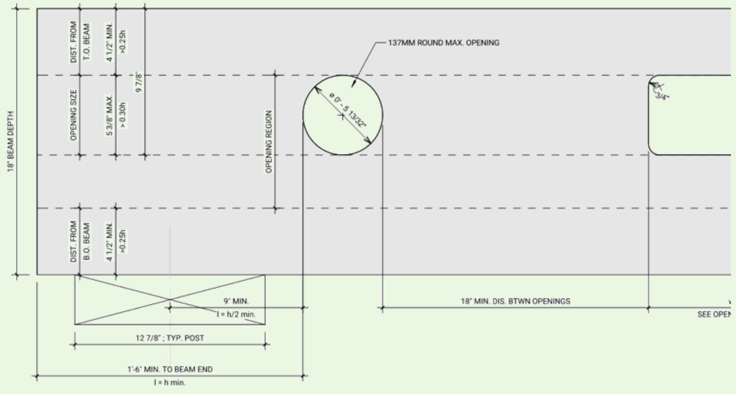


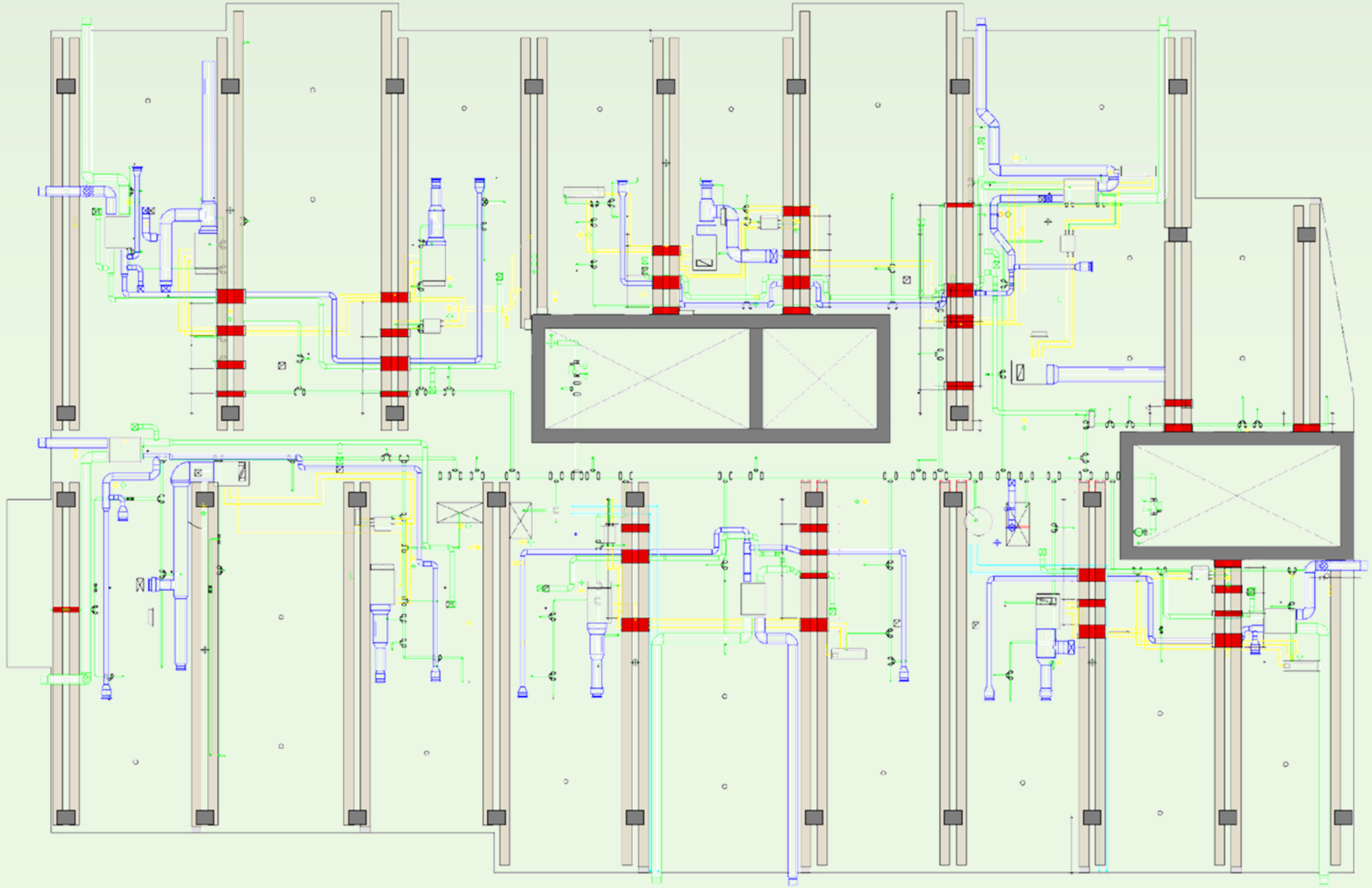
PH ENVELOPE ALLOWED FOR SMALLER SYSTEMS
HIGHER DENSITY FEASIBILE WITH REDUCED FLOOR TO FLOOR HEIGHT

MASS TIMBER AND PASSIVE HOUSE **SYNERGISTIC BENEFITS**

MINIMIZED STRUCTURAL PENETRATIONS

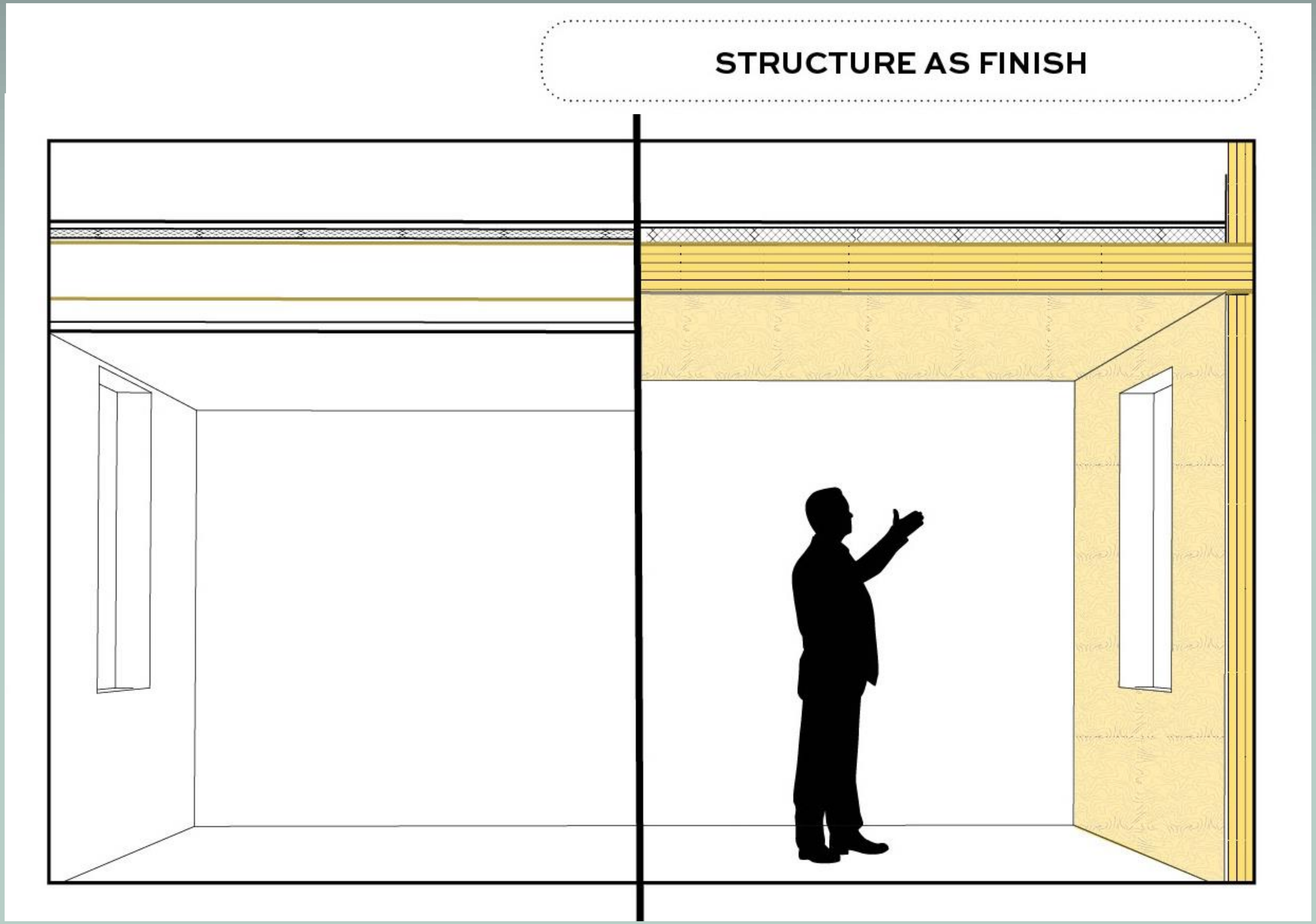
- BEAM PENETRATIONS REQUIRED
- LARGEST PENETRATION H= 5 3/8"
- LARGEST DUCT Ø=4"





BETTER ENVELOPE, SMALLER SYSTEMS – FIT WITHIN REDUCED FLOOR TO FLOOR HEIGHT

MASS TIMBER **EMBODIED CARBON BENEFITS**



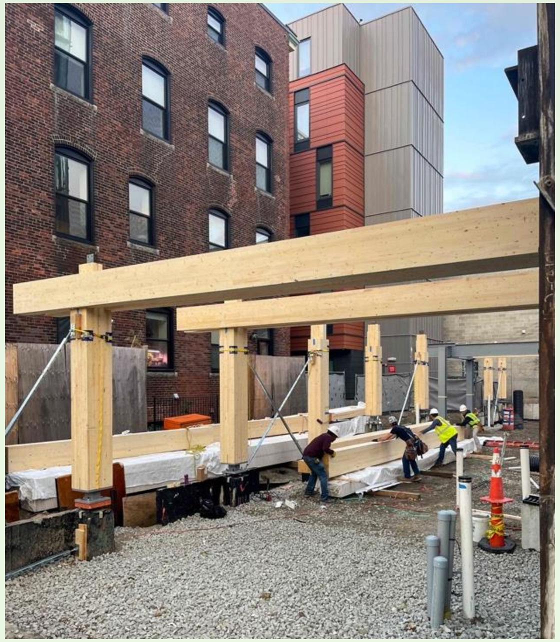
11 E LENOX

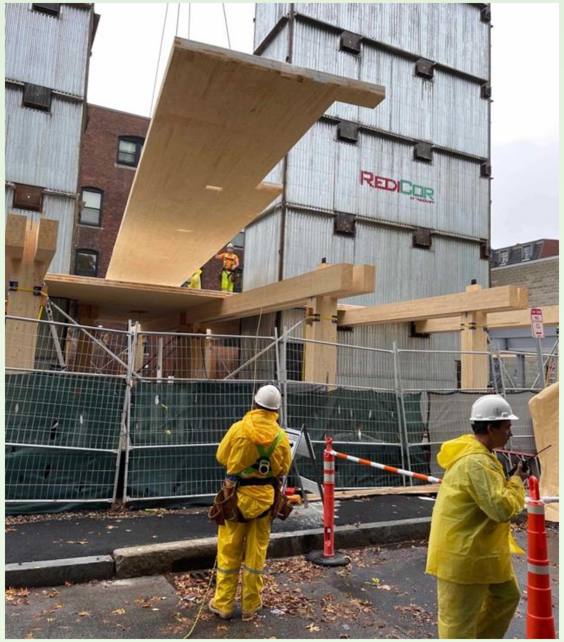
MORE THAN HALF OF CEILINGS ARE EXPOSED CLT

34 UNIT MULTI-FAMILY
SAVED 37,215 SF OF WALL BOARD (1163 sheets) – 10,309 kgO2e
SAVED 1247 LBS OF PAINT

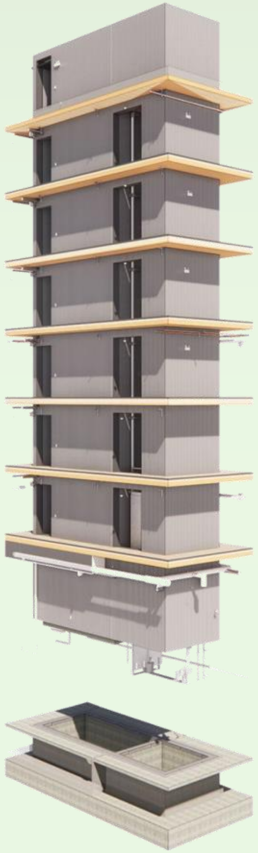
REDUCED USE OF FINISHES

STRUCTURAL SYSTEM AND CORES





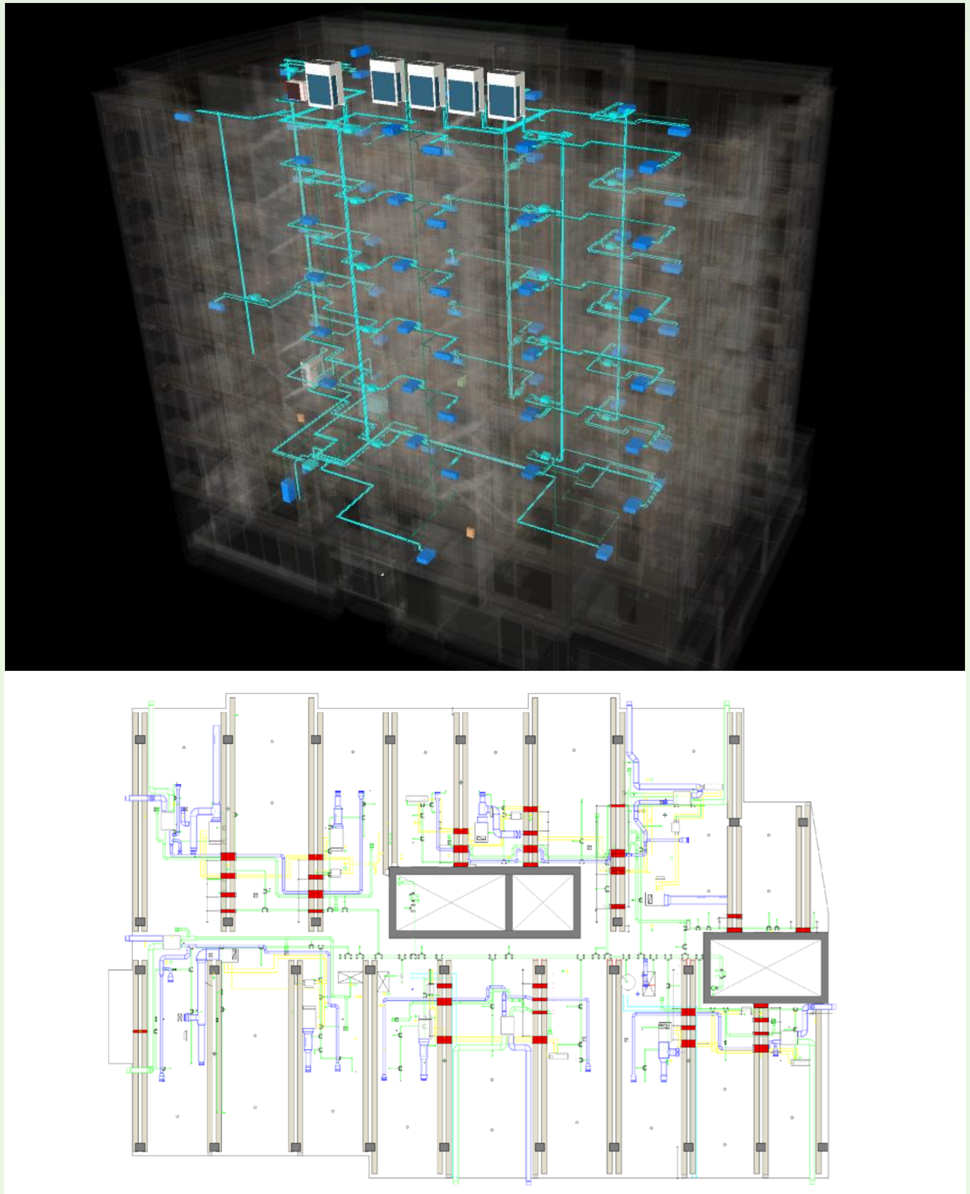
11 E LENOX – CLT PODIUM



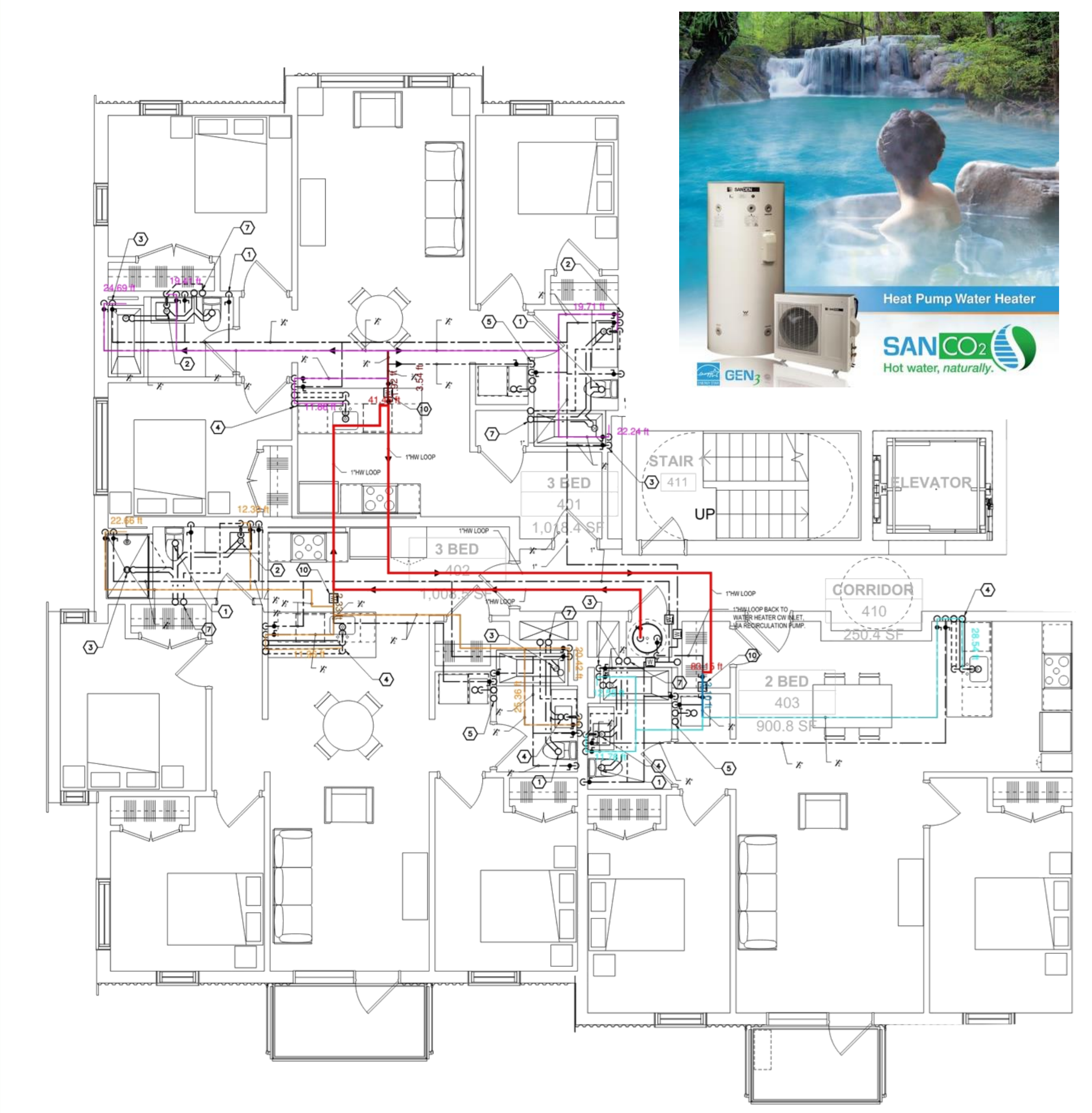
CLT CORE INSTEAD OF REDICOR:
SAVES 276 cu yd CONCRETE
SAVES 8,154 sf STEEL FORMS
ADDS 106,931 kgCO2e CARBON STORAGE

COMPOSIT PREFAB MODULES FOR VERTICAL CORES

HVAC AND HOT WATER SYSTEMS AND LAYOUTS



HVAC SYSTEMS – **VRF w/r-410 REFRIGERANT**



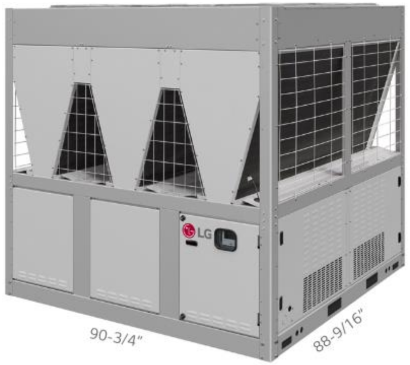
DOMESTIC HOT WATER – **SANDEN CO2 PLUMBING LAYOUT**

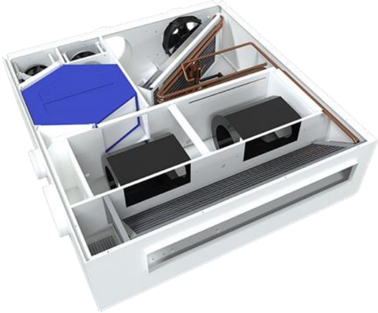
COMPARISON OF THE CARBON IMPACTS of mainstream HVAC and Hot Water System Choices at 11 E Lenox, Boston

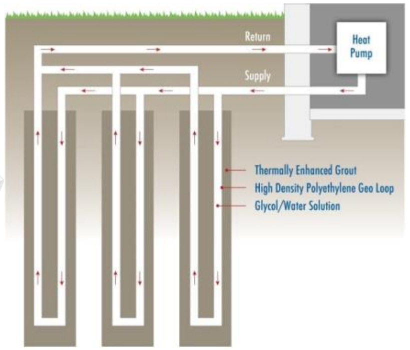
- Passive House Multifamily Building in Boston, MA
- WUFI used to energy model HVAC cases against each other.
    - All systems use a 20 year analysis time period for energy and refrigerant
    - The building has 34 apartments, 106 people, and 36,394 sq ft
    - R32 has been used instead of R410A due to phase out.
- Hot water modeled with spreadsheets & WUFI
    - 6.6 gallons per person per day
- Equipment, piping, ductwork and accessories accounted for in the weight of each system and a simplified 1 to 9 lbs CO_2e / lb of equipment* depending on complexity used to arrive at the embodied carbon of the systems. * This is a very difficult number to attain and verify
- Refrigerants impacts are quantified using a leakage model and GWP20

HEATING AND COOLING INVESTIGATION

VRF…………Mini Split…………..Hybrid VRF…Heat Pump Hydronic…All-in-one……Geothermal







Heating and Cooling: VRF (Variable Refrigerant Flow) * *Final System*

Pieces of Equipment

- Daikin VRV (VRF)
- 81x ducted indoor units
- 5x six-ton VRF outdoor units
- 1x twelve-ton VRF outdoor units
- 37x branch controllers
- 36x Small ERVs (Panasonic FV-10VEC2)
- Refrigerant Piping
- Conditioning and Ventilatior Ductwork Room-by-room

Critical Statistics

- 12,100 lbs of equipment
- 1129 lbs of refrigerant piping
- 20,000 lbs of ductwork and accessories
- 214 lbs of R-32 Refrigerant
- ***Annual Leak Rate: 6%***
- ***EUI: 3.54 kBTU/sqft/yr***

HEATING AND COOLING INVESTIGATION

Heating and Cooling: Mini Splits

Pieces of Equipment

- Daikin Aurora Mini-Splits
- 81x horizontal ducted indoor units
- 81x mini-split outdoor units
- 81x Small ERVs (Panasonic FV-10VEC2)
- Refrigerant Piping
- Conditioning and Ventilation Ductwork Room-by-room

Critical Statistics

- 11,200 lbs of equipment
- 791 lbs of refrigerant piping
- 20,000 lbs of ductwork and accessories
- 128 lbs of R-32 Refrigerant
- ***Leak Rate: 5.3%***
- ***EUI: 3.81 kBTU/sqft/yr***

Heating and Cooling: Hybrid VRF (Variable Refrigerant Flow + Hydronics)

Pieces of Equipment

- Mitsubishi Hybrid VRF
- 81x ducted indoor units
- 3x ten-ton VRF outdoor units
- 1x twelve-ton VRF outdoor units
- 7x branch controllers
- 36x Small ERVs (Panasonic FV-10VEC2)
- Refrigerant Piping
- Hydronic Piping / Accessories
- Conditioning and Ventilation Ductwork Room-by-room

Critical Statistics (Preliminary)

- *Unknown weight of equipment, refrigerant piping, hydronic piping and accessories, assuming 30% more than Standard VRF for now*
- *20,000 lbs of ductwork and accessories*
- *116 lbs of R-32 Refrigerant*

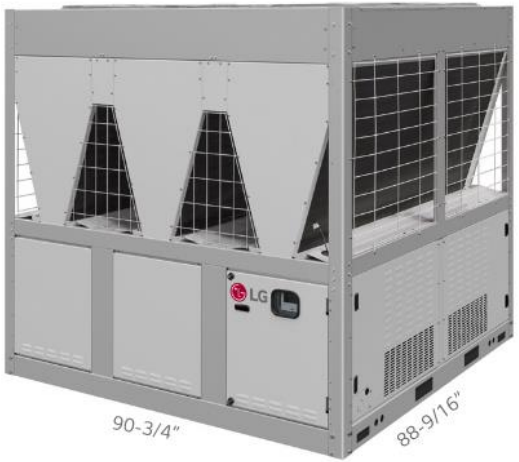
Annual Leak Rate: 5.3%

EUI: 3.64 kBTU/sqft/yr

Heating and Cooling: Heat Pump Hydronic

Pieces of Equipment

- 1x 48 ton LG Air cooled inverter heat pump chiller
- 85x ducted fan-coil units
- 81x Small ERVs (Panasonic FV-10VEC2)
- 4-pipe Hydronic Piping
- Conditioning and Ventilation Ductwork Room-by-room



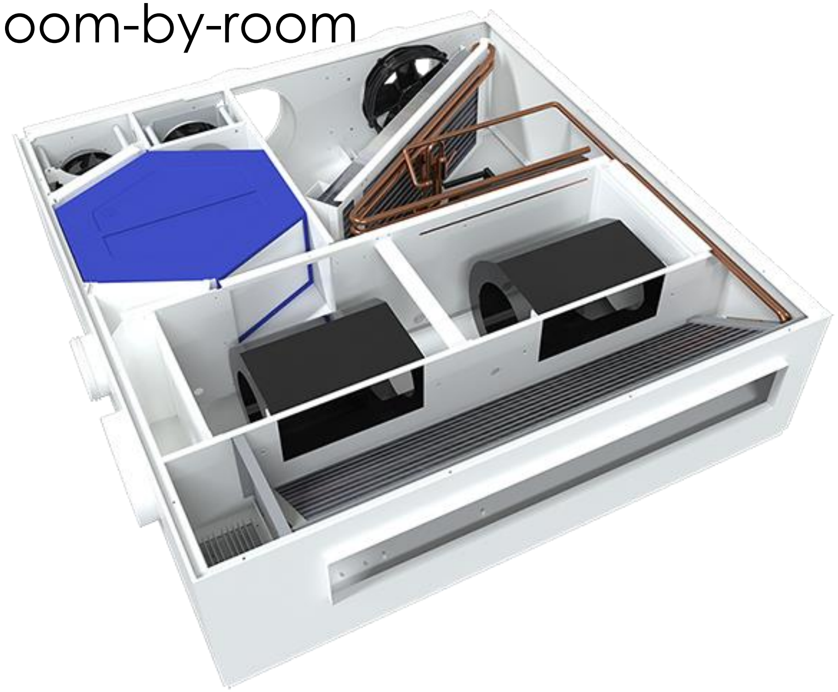
Critical Statistics

- 16,000 lbs of equipment
- 17,500 lbs of water piping
- 20,000 lbs of ductwork and accessories
- 93 lbs of R-32 Refrigerant
- ***Leak Rate: 3%***
- ***EUI: 3.8 kBTU/sqft/yr***

Heating and Cooling: All-in-One (Ephoca, Minotair)

Pieces of Equipment

- 85x horizontal Ephoca heat pump/ERVs
- Conditioning and Ventilation Ductwork Room-by-room



Critical Statistics

- 16,200 lbs of equipment
- ***0 lbs of refrigerant piping***
- 12,000 lbs of ductwork and accessories
- 116 lbs of R-32 Refrigerant
- ***Leak Rate: 2%***
- ***EUI: 4.00 kBTU/sqft/yr***

HEATING AND COOLING INVESTIGATION

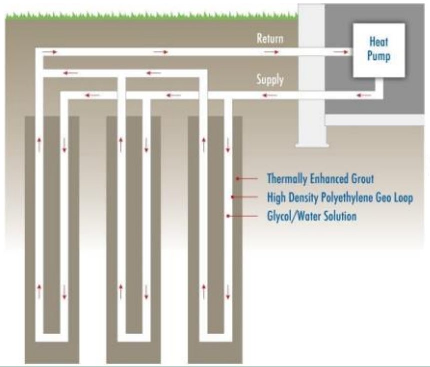
Heating and Cooling: Geothermal

Pieces of Equipment

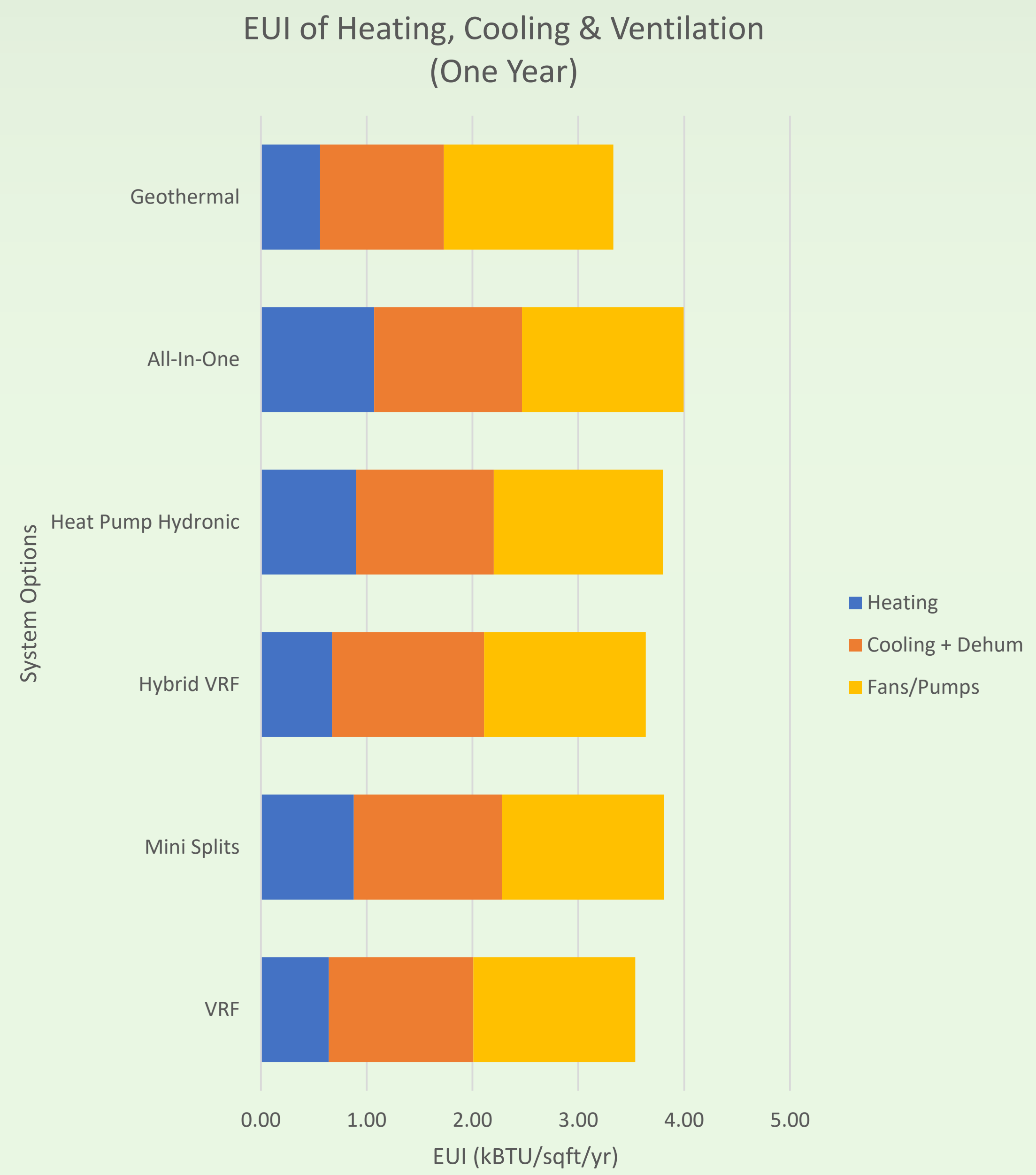
- 85x water-to-air heat pumps (waterfurnace)
- 81x Small ERVs (Panasonic FV-10VEC2)
- 2-pipe Geothermal Piping
- Conditioning and Ventilation Ductwork Room-by-room

Critical Statistics

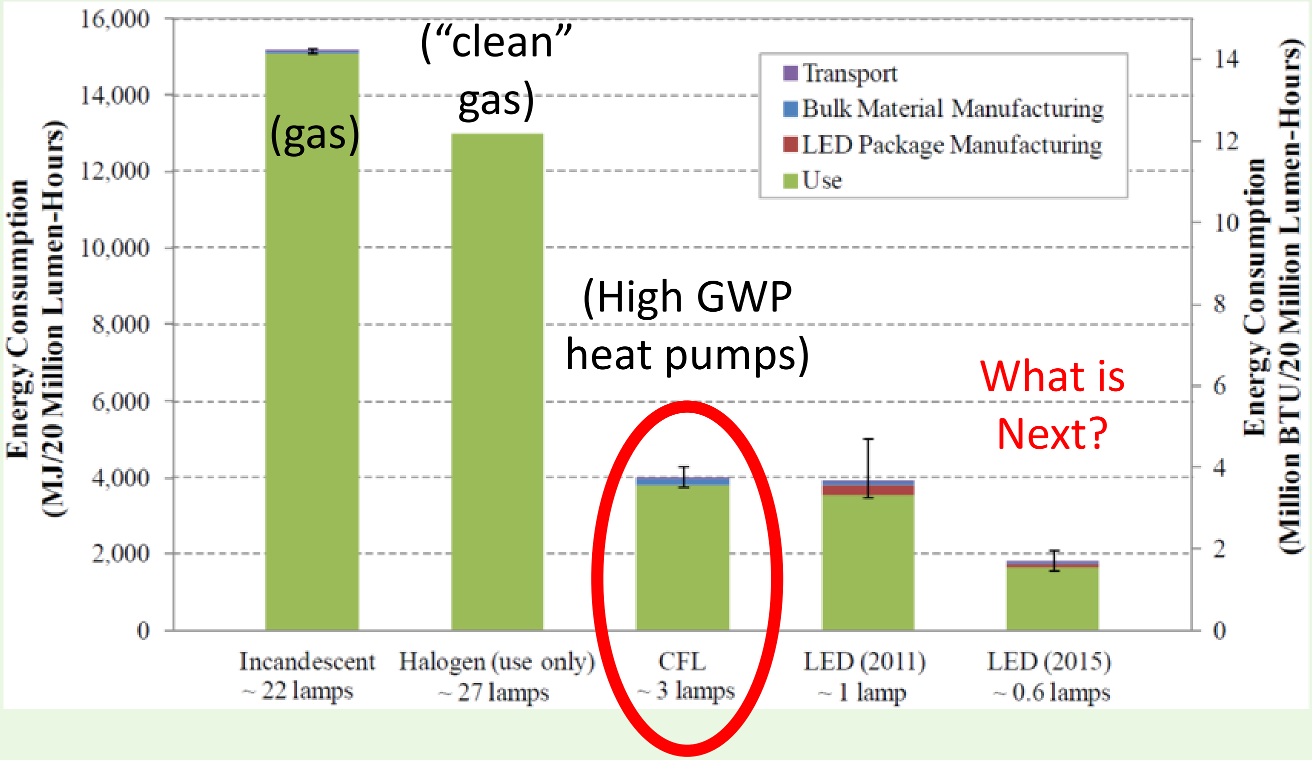
- 10,200 lbs of equipment
- 22,600 lbs of water piping
- 20,000 lbs of ductwork and accessories
- 127 lbs of R-32 Refrigerant
- ***Leak Rate: 2%***
- ***EUI: 3.3 kBTU/sqft/yr***



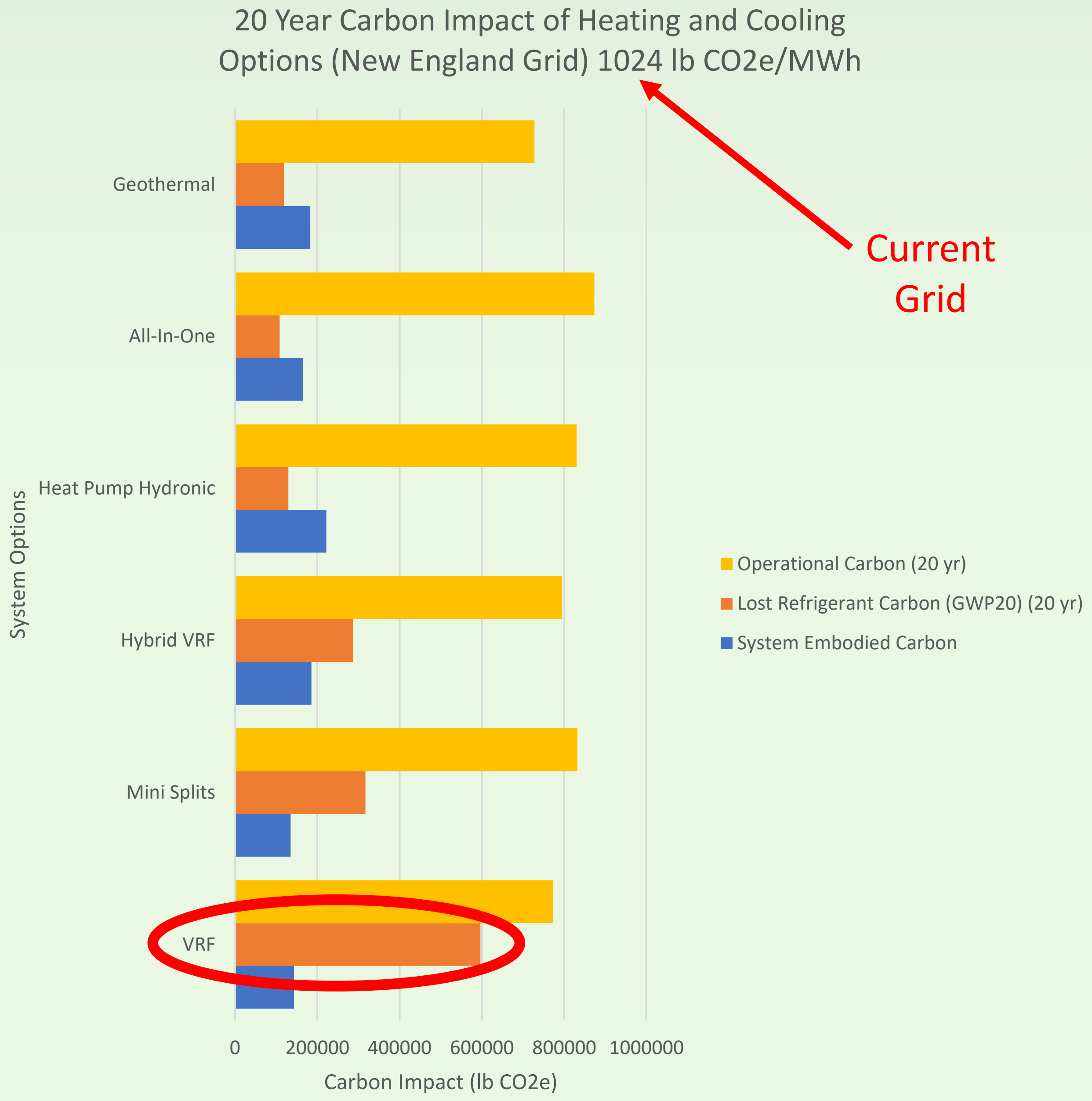
HEATING AND COOLING INVESTIGATION RESULTS - ENERGY



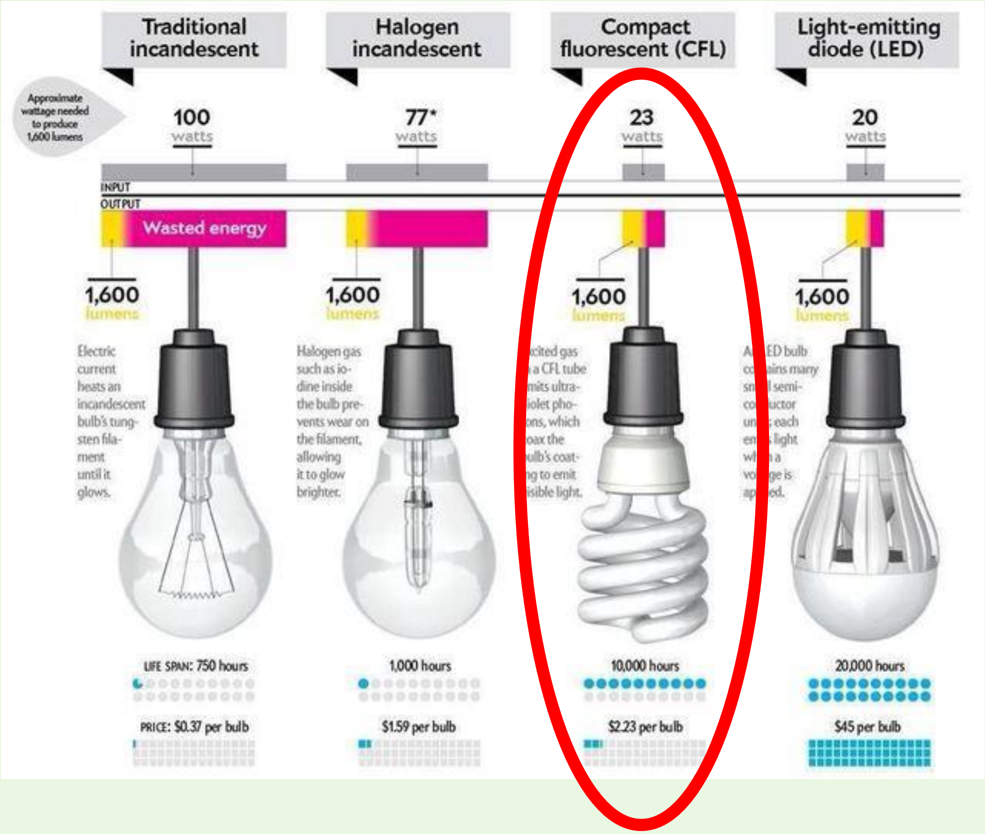
The Incandescent-CFL-LED Analogy:



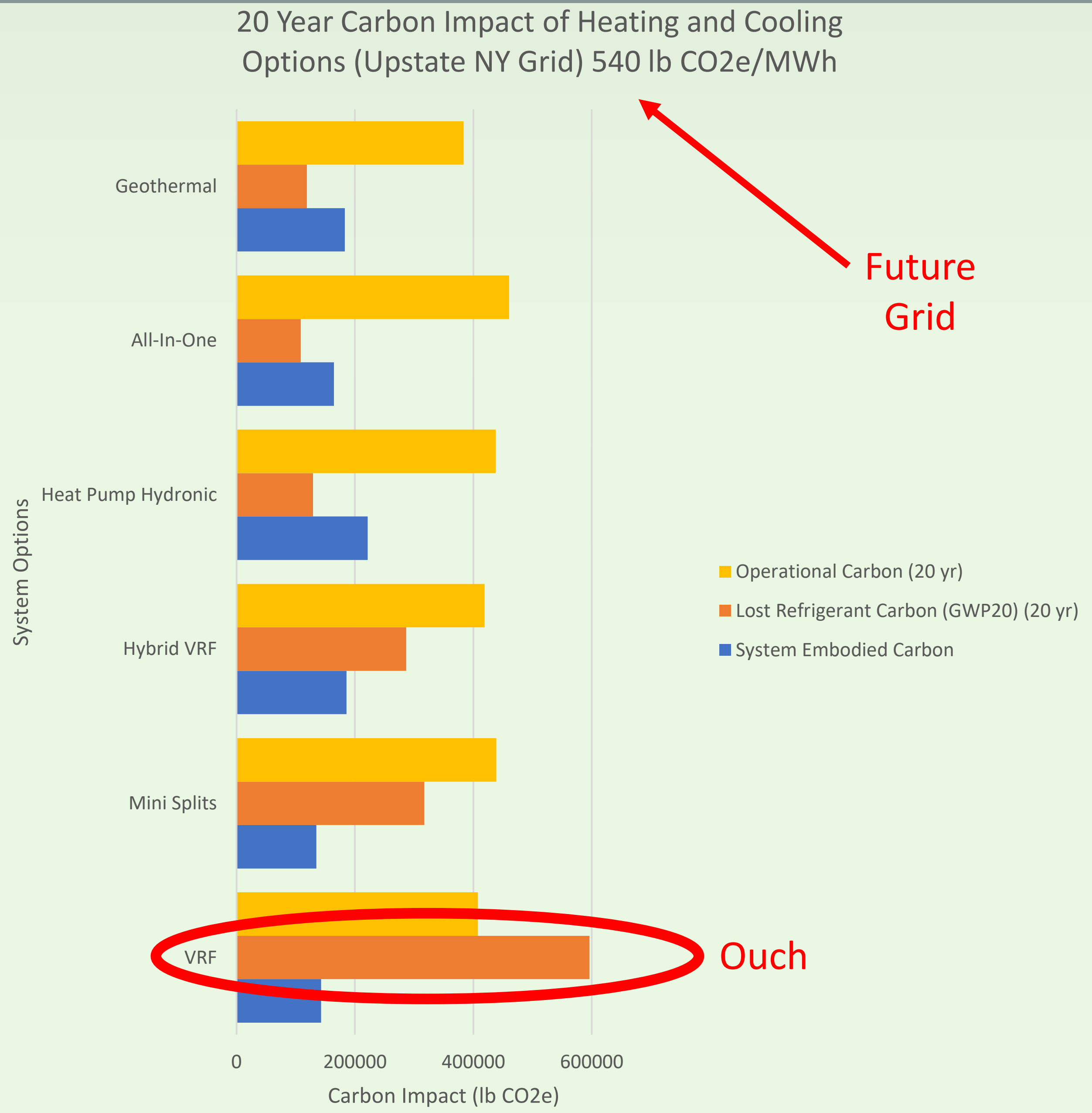
HEATING AND COOLING INVESTIGATION RESULTS - GWP



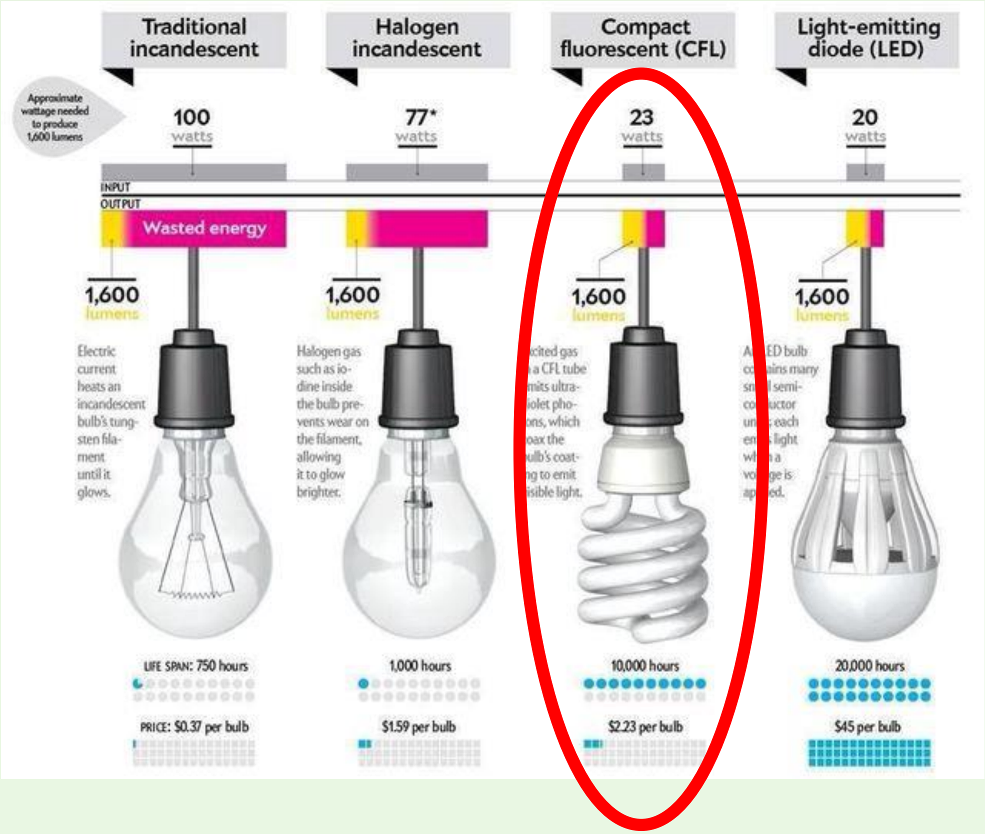
The Incandescent-CFL-LED Analogy:



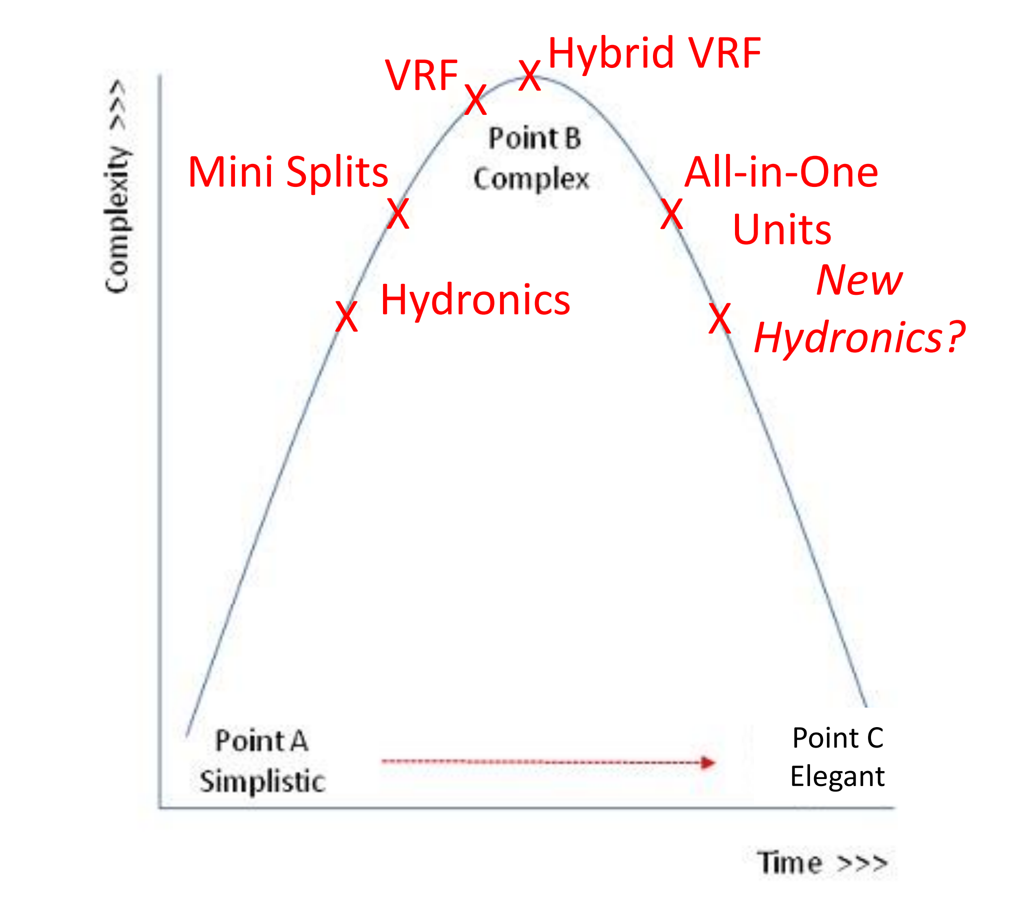
HEATING AND COOLING INVESTIGATION RESULTS - GWP



The Incandescent-CFL-LED Analogy:



HEATING AND COOLING INVESTIGATION RESULTS - THOUGHTS



The Product Complexity Curve

The VRF Conundrum:

+ *VRF is a well designed product family*
- *VRF has too much refrigerant and is leaky*

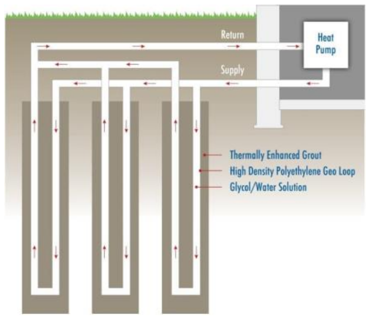
What is Next?

- ***Easy:*** ***More all-in-one units that drastically reduce the amount of field installed piping and ductwork.***
- ***Hard:***

Carbon impacts of heat pump technology appear to be approaching a low limit, but we are not at ZERO, and nowhere near net POSITIVE.

HEAT PUMP DOMESTIC HOT WATER INVESTIGATION

2 Apartments per R134A Tank HP…3 Apartments per CO_2 HP…Central CO_2 HP Systems…. Geothermal...VRF Hydro



Hot Water: 3 Apartment per Distributed CO_2 Split Heat Pumps * *Final System*

Pieces of Equipment

- 12x CO_2 heat pump hot water heaters
- 12x 83-gallon hot water storage tanks
- 12x expansion tanks
- 12x recirculation pumps

Critical Statistics

- 4476 lbs of equipment
- 1200 lbs of hot water piping
- 36 lbs of CO_2 refrigerant
- ***Leak Rate: 1%***
- ***EUI: 4.54 kBTU/sqft/yr (Primary @ 19.5 gpd)***
- ***EUI: 1.58 kBTU/sqft/yr (Primary @ 6.6 gpd)***
- ***EUI: 0.07 kBTU/sqft/yr (Recirc)***

Hot Water: 2 Apartment per Distributed R-134A Tank Heat Pumps

Pieces of Equipment

- 17x 80 gallon tank type heat pump hot water heaters
- 17x expansion tanks

Critical Statistics

- 4300 lbs of equipment
- 1000 lbs of condensate piping and ductwork
- 15.3 lbs of R-134A Refrigerant
- ***Leak Rate: 1%***
- ***EUI: 4.94 kBTU/sqft/yr (@ 19.5 gpd)***
- ***EUI: 1.72 kBTU/sqft/yr (@ 6.6 gpd)***

Hot Water: Central *CO2 with HP Recirc (CO2 + R-134A)*

Pieces of Equipment

- 6x CO2 heat pump hot water heaters
- 6x 120-gallon hot water storage tanks
- 1x expansion tank
- 1x heat pumps to handle recirculation losses
- 4x recirculation pump

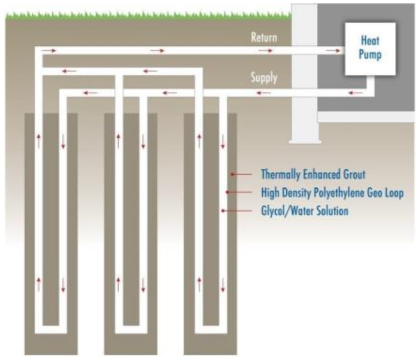
Critical Statistics

- 3680 lbs of equipment
- 1414 lbs of hot water piping
- 1 lbs of R-134A Refrigerant
- 18 lbs of CO2 refrigerant
- ***Leak Rate: 1%***
- ***EUI: 4.54 kBTU/sqft/yr (Primary @ 19.5 gpd)***
- ***EUI: 1.58 kBTU/sqft/yr (Primary @ 6.6 gpd)***
- ***EUI: 0.07 kBTU/sqft/yr (Recirc)***

Hot Water: Central *Geothermal*

Pieces of Equipment

- 1x nine-ton Water-to-water heat pump (Waterfurnace NEW)
- 8x 120-gallon hot water storage tanks
- 1x expansion tank
- 1x recirculation pump
- 2x equipment pumps



Critical Statistics

- 2800 lbs of equipment
- 7200 lbs of hot water piping
- 4 lbs of R134-A refrigerant
- ***Leak Rate: 1%***
- ***EUI: 4.68 kBTU/sqft/yr (Primary @ 19.5 gpd)***
- ***EUI: 1.63 kBTU/sqft/yr (Primary @ 6.6 gpd)***
- ***EUI: 0.07 kBTU/sqft/yr (Recirc)***

Hot Water: Central *VRF*

Pieces of Equipment

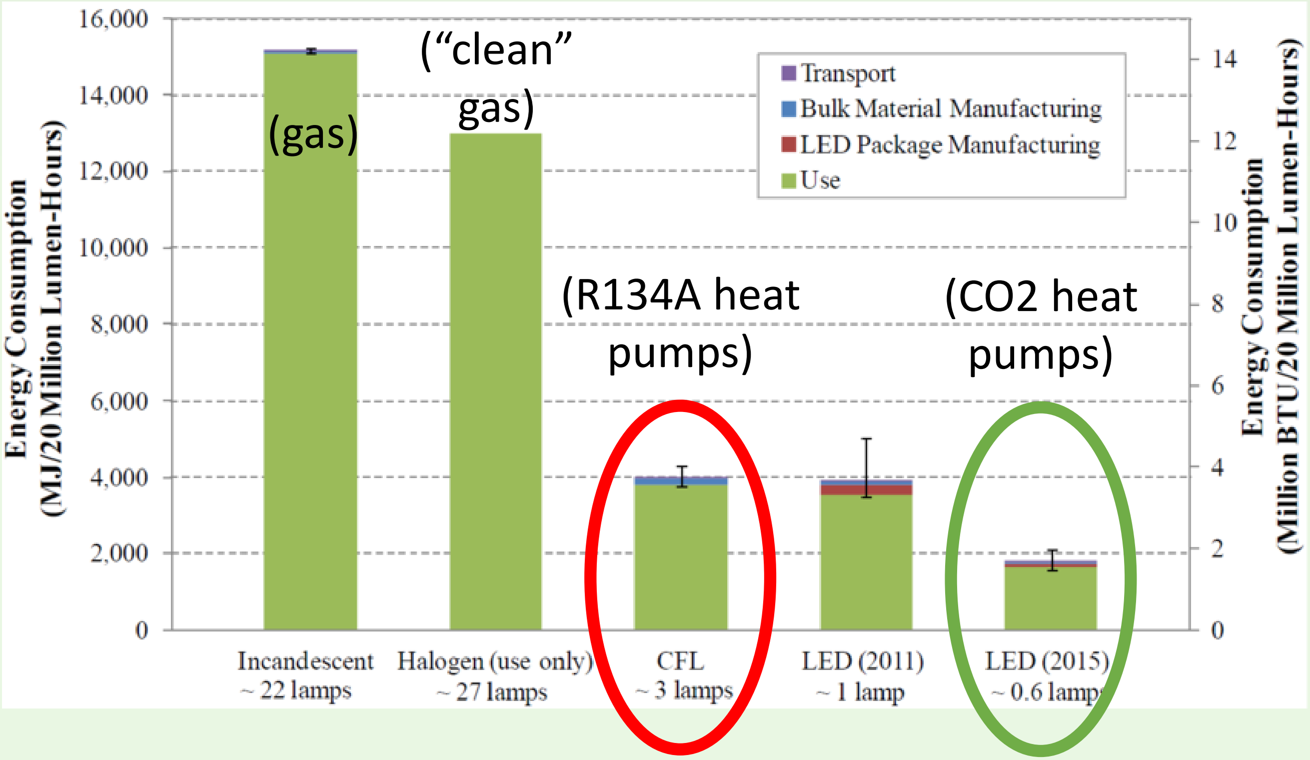
- 1x ten-ton VRF outdoor Unit (LG)
- 2x hydro-kit refrigerant-to-water heat pump (LG)
- 8x 120-gallon hot water storage tanks
- 1x expansion tank
- 1x recirculation pump
- 2x equipment pumps

Critical Statistics

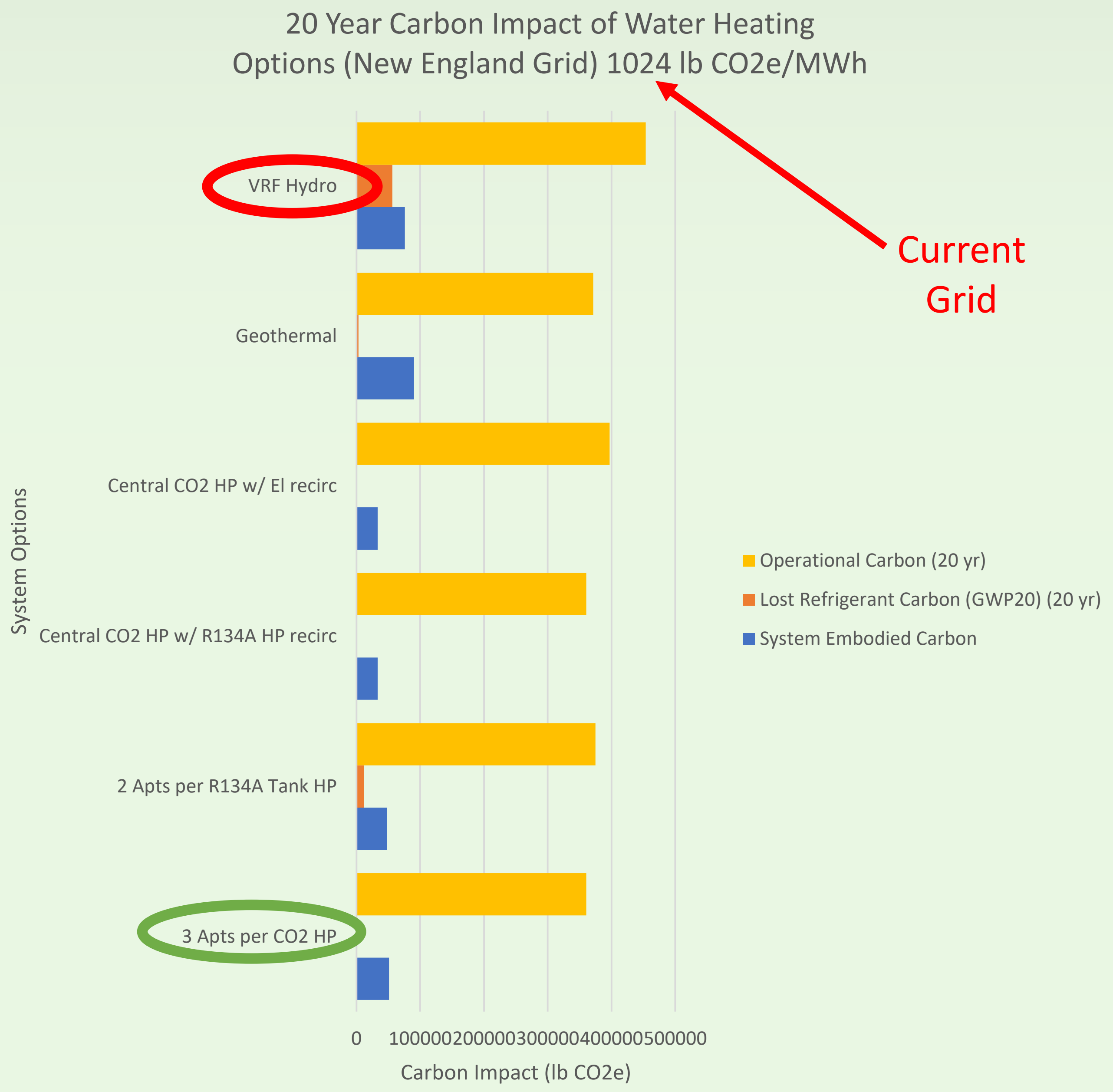
- 3917 lbs of equipment
- 4523 lbs of hot water piping
- 19.8 lbs of R-32 refrigerant
- 9.9 lbs of R-134A refrigerant
- **Leak Rate: 5.3% VRF / 1% Hydro Kit**
- **EUI: 5.75 kBTU/sqft/yr (*Primary @ 19.5 gpd*)**
- **EUI: 1.99 kBTU/sqft/yr (*Primary @ 6.6 gpd*)**
- **EUI: 0.09 kBTU/sqft/yr (Recirc)**

HEAT PUMP DOMESTIC HOT WATER RESULTS - Energy

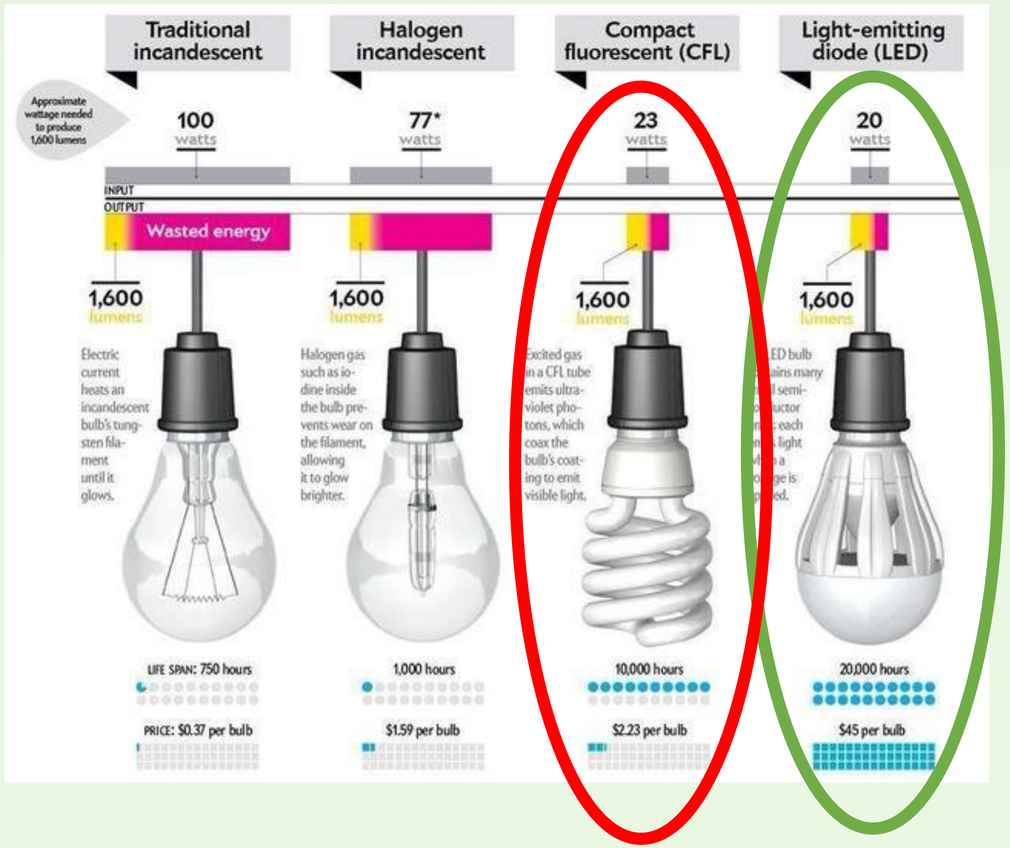
The Incandescent-CFL-LED Analogy:



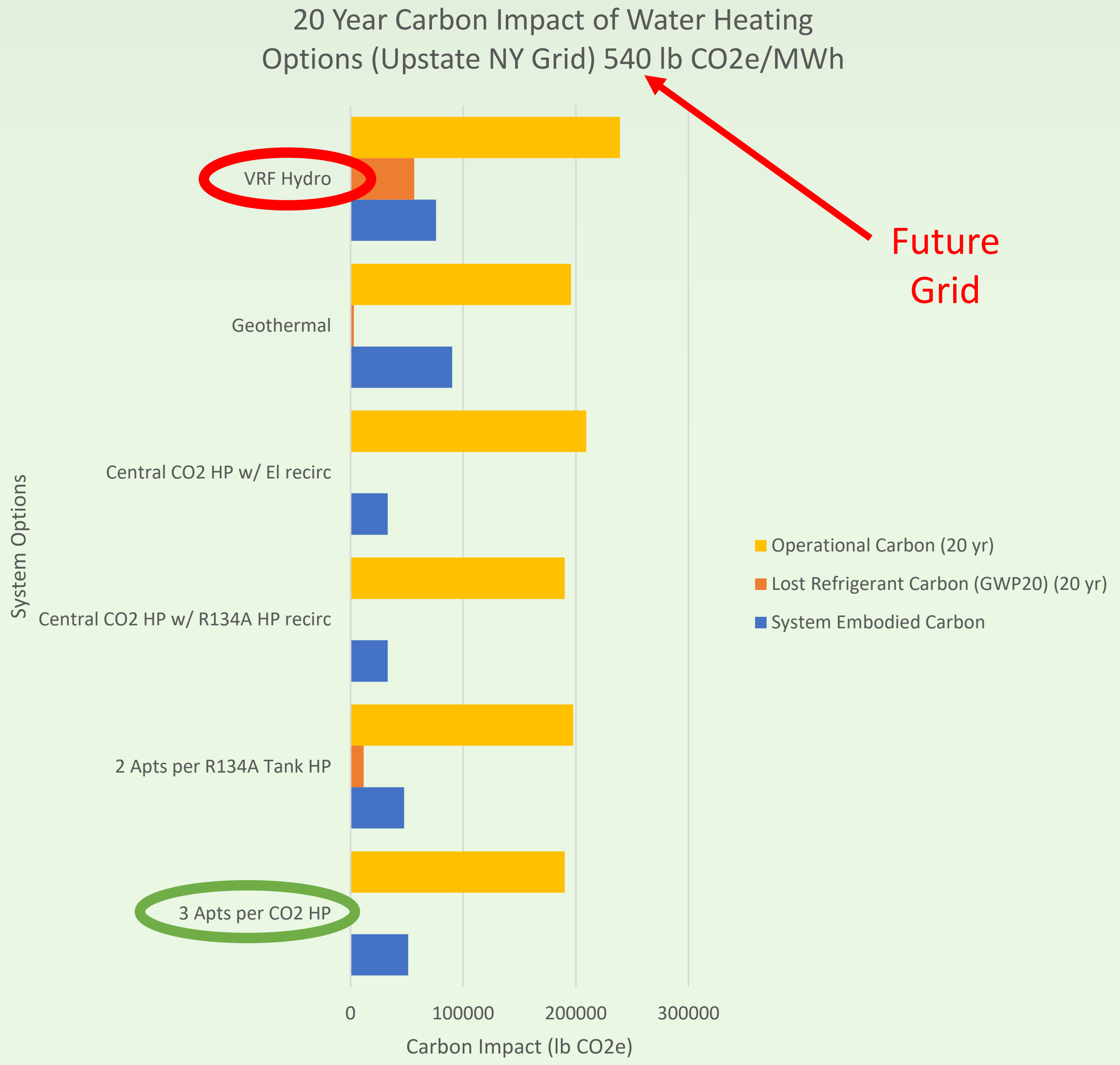
HEAT PUMP DOMESTIC HOT WATER RESULTS - GWP



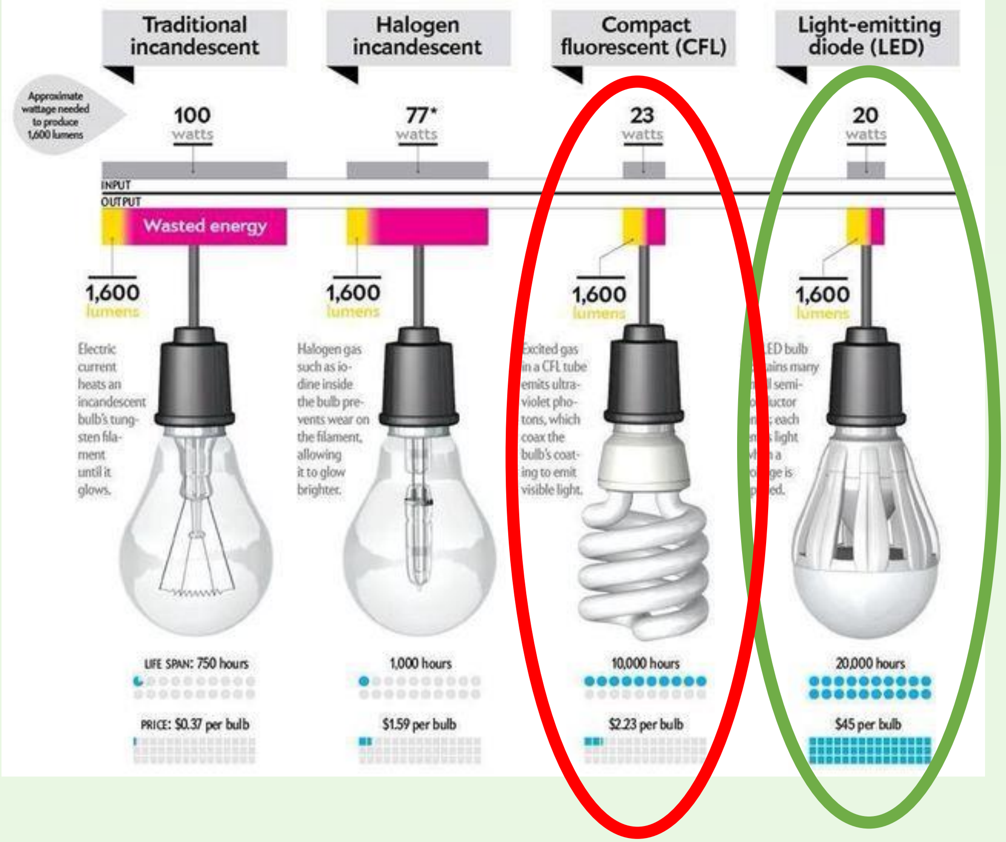
The Incandescent-CFL-LED Analogy:



HEAT PUMP DOMESTIC HOT WATER RESULTS - GWP



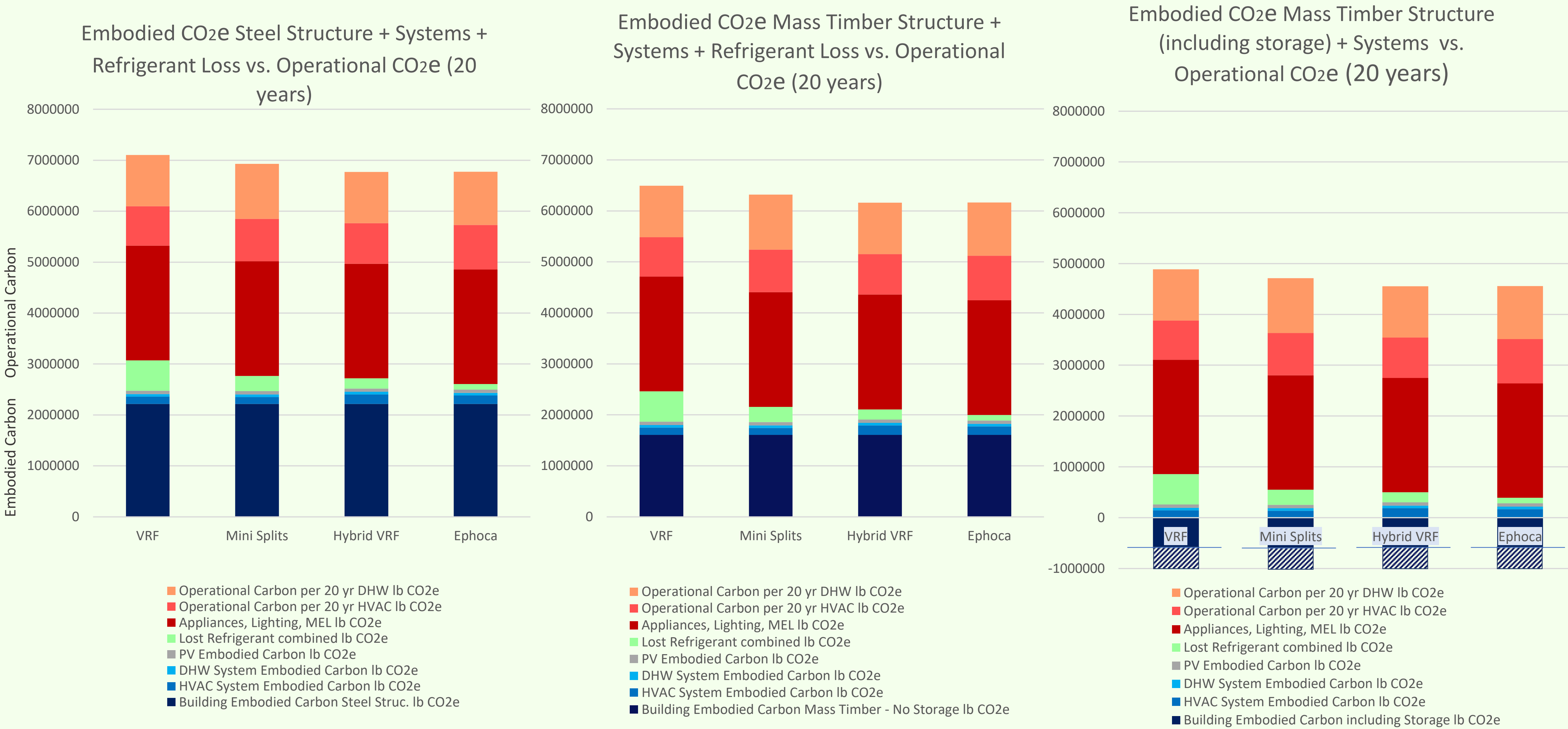
The Incandescent-CFL-LED Analogy:



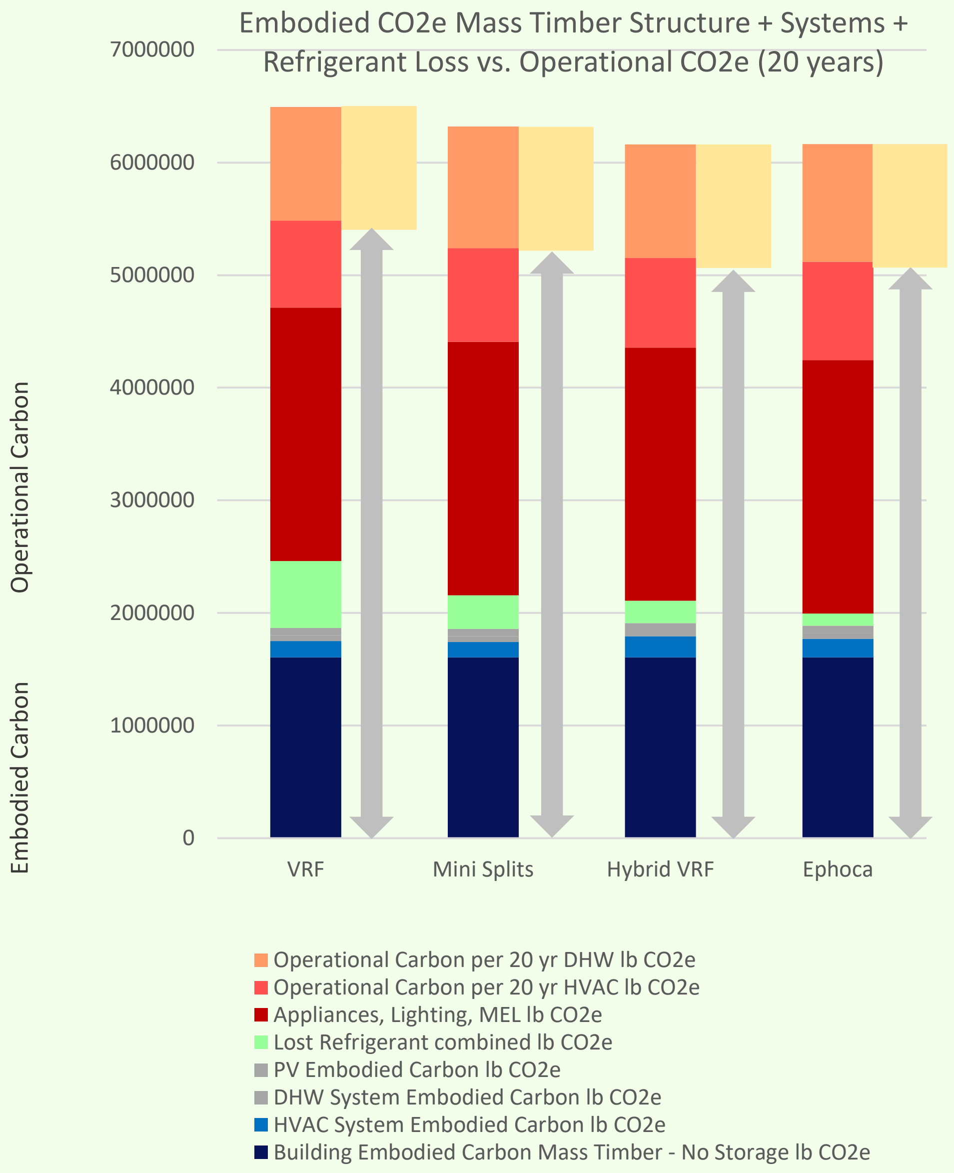
APPROACHING MAXIMUM EFFICIENCY

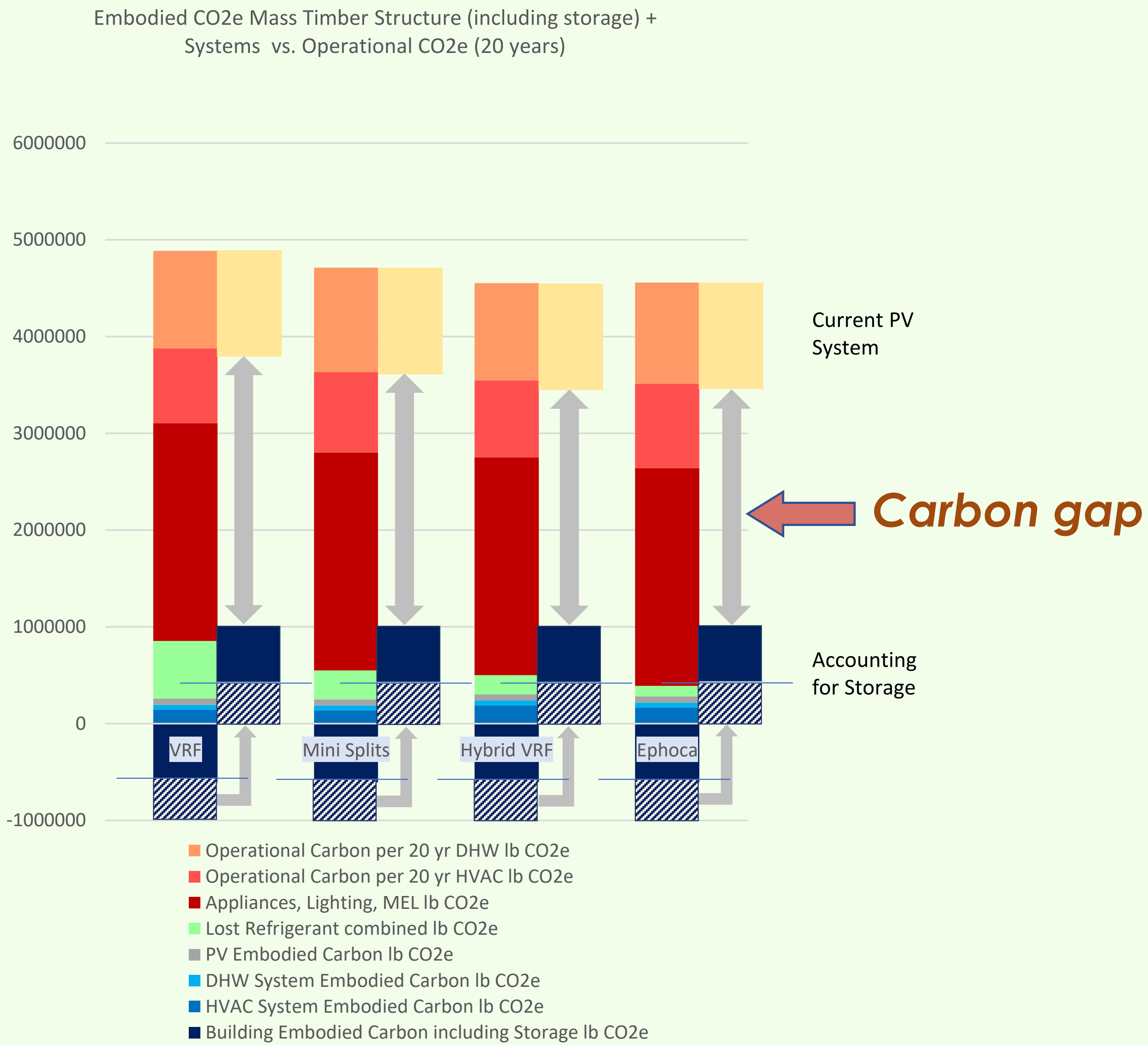
Envelope is optimized.

Systems are almost as efficient they can be.
How close to zero are we?

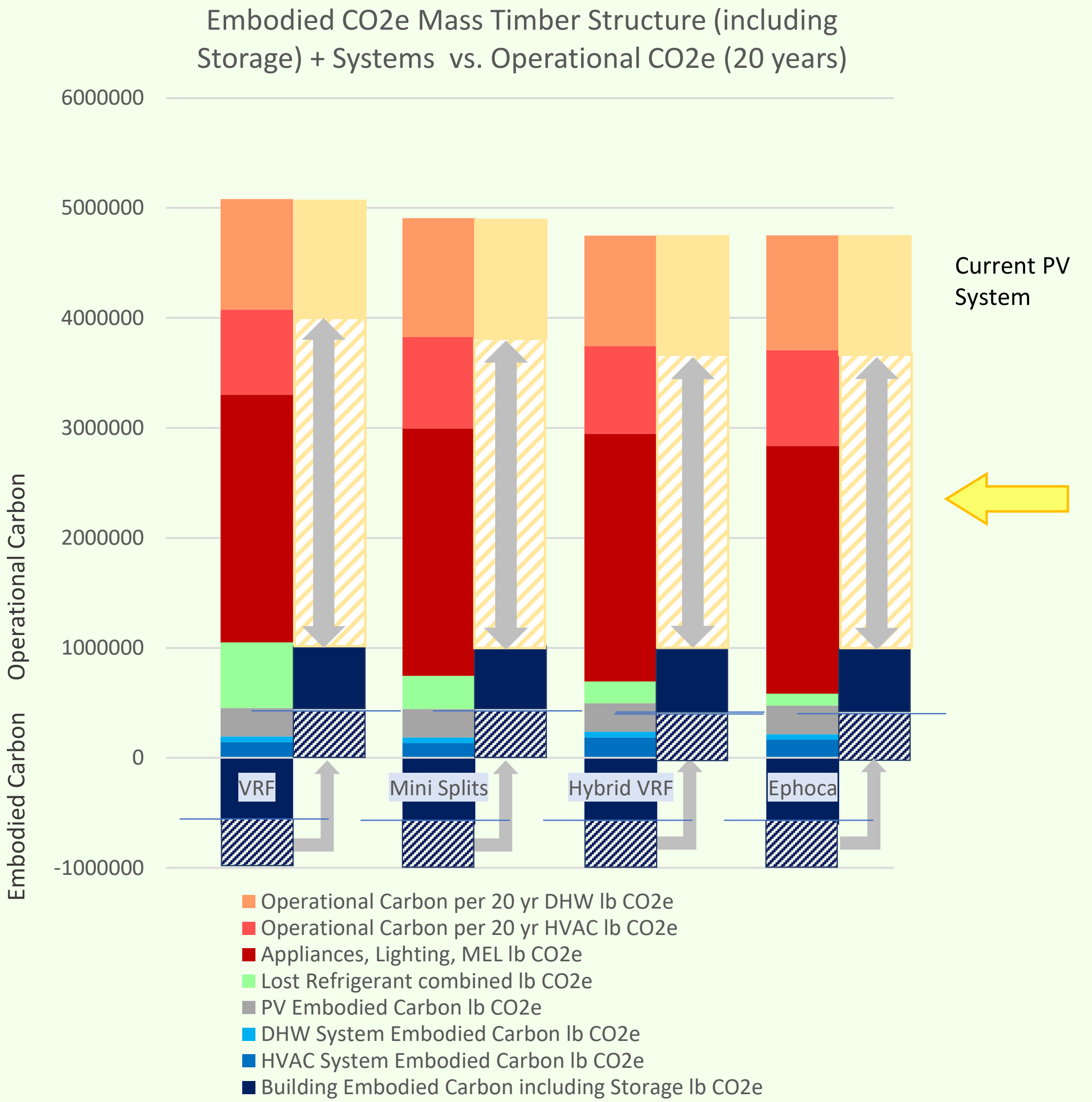


EMBODIED vs. 20 YEARS OPERATIONAL CARBON





EMBODIED vs. 20 YEARS OPERATIONAL CARBON



Added solar to close the gap for 20 years combined EC and operations

REDUCTION, CAPTURE, STORAGE OF CARBON CAN HELP

CLOSE THE CARBON GAP

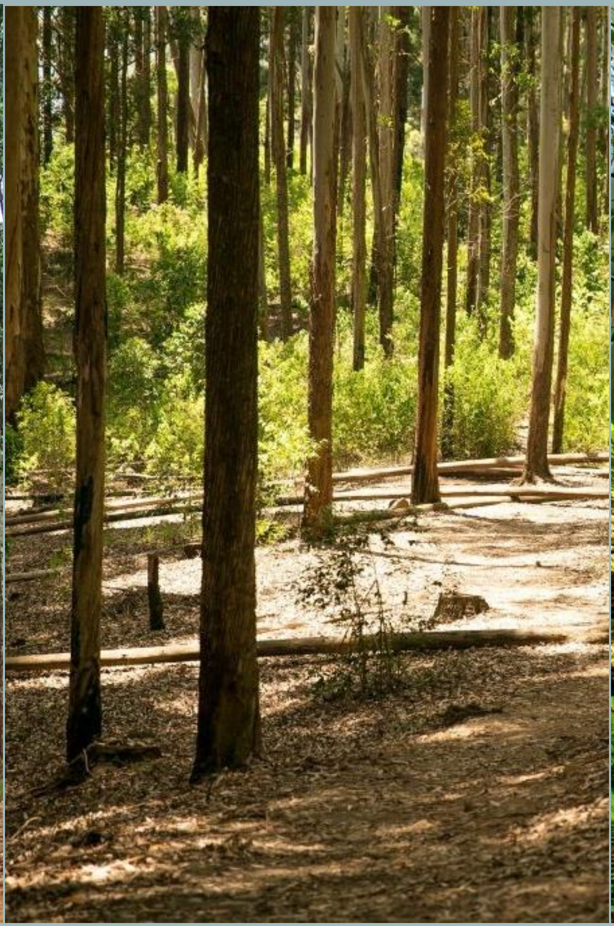
IS MASS TIMBER A PATH TO **DECARBONIZATION?**

Carbon 12 Condominium Building, Portland Oregon, Kaiser Path

The Bullitt Center, The Miller Hull Partnership, DCI Engineers, (Photo: John Stamets)

Sure, its pretty – but will it save us?

NOT ALL FORESTS ARE **EQUAL**



UNMANAGED - PLANTATIONS - SELECTIVE CUTTING - OLD GROWTH

FOREST “TYPES”

NOT ALL MANAGEMENT IS **EQUAL** - PLANTATIONS – SELECTIVE CUTTING

LOW BIODIVERSITY– LOW CARBON ON LAND- HIGH CARBON IN WOOD – LOW ECOSYSTEM SERVICES – HIGH FORESTRY PRODUCTS

MODERATE – GOOD BIODIVERSITY– MODERATE CARBON ON LAND- HIGHEST CARBON IN WOOD – MODERATE ECOSYSTEM SERVICES – MODERATE BUT CONSISTENT FORESTRY PRODUCTS

RANGE OF BENEFITS - BIODIVERSITY– CARBON ON LAND- CARBON IN WOOD – ECOSYSTEM SERVICES – FORESTRY PRODUCTS

CERTIFICATIONS WHAT ARE THEY, WHAT DO THEY ACCOMPLISH ?

THIS IS A CERTIFIED FOREST – CLEAR-CUTTING OF OLD GROWTH IN BC CANADA

NOT ALL FORESTS ARE EQUAL

OLD GROWTH FORESTS MUST BE PRESERVED COMPLEX SYSTEMS SHOULD NOT BE REDUCED TO SIMPLE SYSTEMS OR MONOCULTURE

HIGHEST BIO-DIVERSITY, FULL RANGE OF ECOSYSTEM SERVICES, LOWER RATES OF CARBON DRAWDOWN, BUT HIGHEST LEVEL OF TOTAL CARBON SEQUESTRATION IN ECOSYSTEM POOL, MINIMAL FORESTRY PRODUCTS
LAUREN COOPER, DIRECTOR, MSU FOREST CARBON AND CLIMATE PROGRAM

"It makes no ecological, social or economic sense to be logging old growth forests as we grapple with the existential threats of climate change and mass extinctions." Dr. Suzanne Simard

OPTIMAL GOAL – CLIMATE SMART

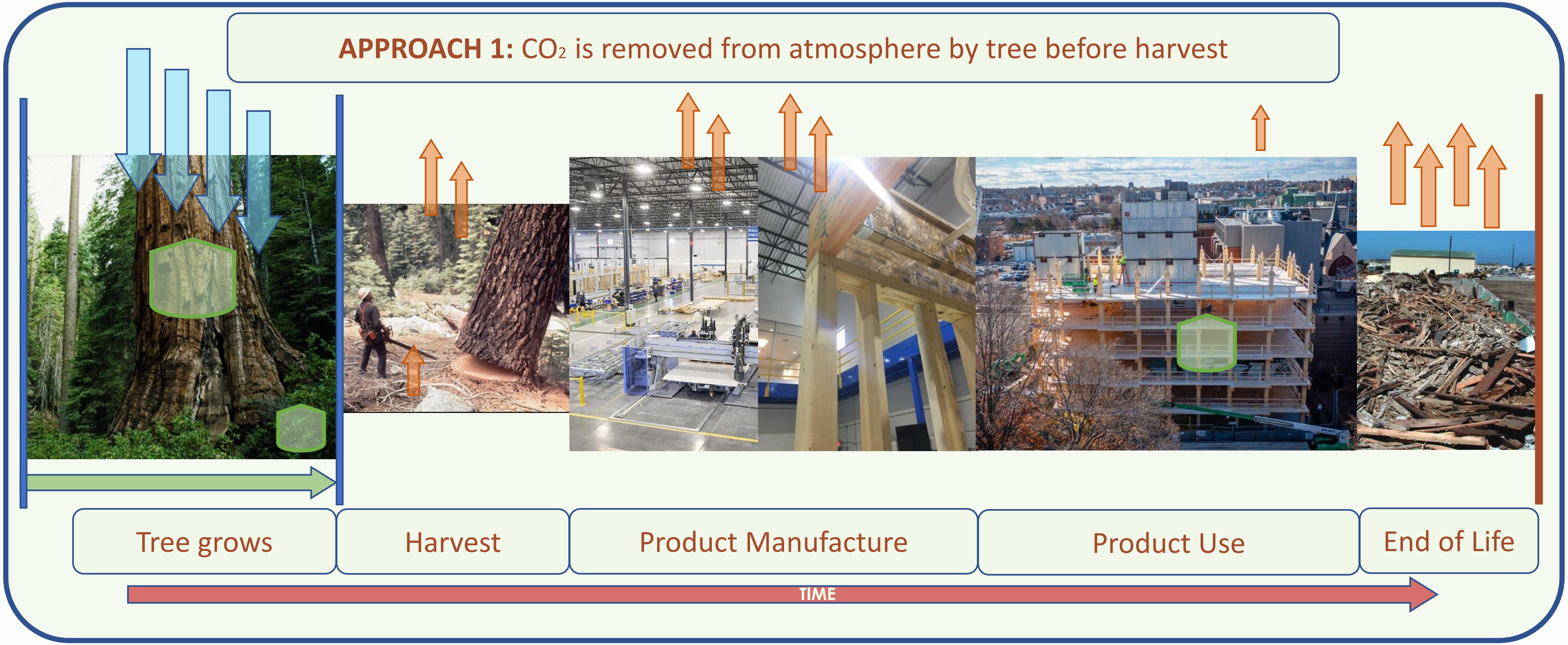
= OPTIMIZED CARBON SEQUESTRATION - ADAPT MANAGEMENT FOR RESILIENT FOREST ECOSYSTEMS - MANAGEMENT FOR INCREASED PRODUCTIVITY - INCLUDING ALL ECOSYSTEMS SERVICES,

(PRESUMABLY)

APPROACHES FOR **CARBON ACCOUNTING**

GROWTH **HARVEST** **PROCESSING AND MANUFACTURE** **USE** **END OF LIFE**

APPROACHES FOR **CARBON ACCOUNTING**



Start accounting when tree starts growing

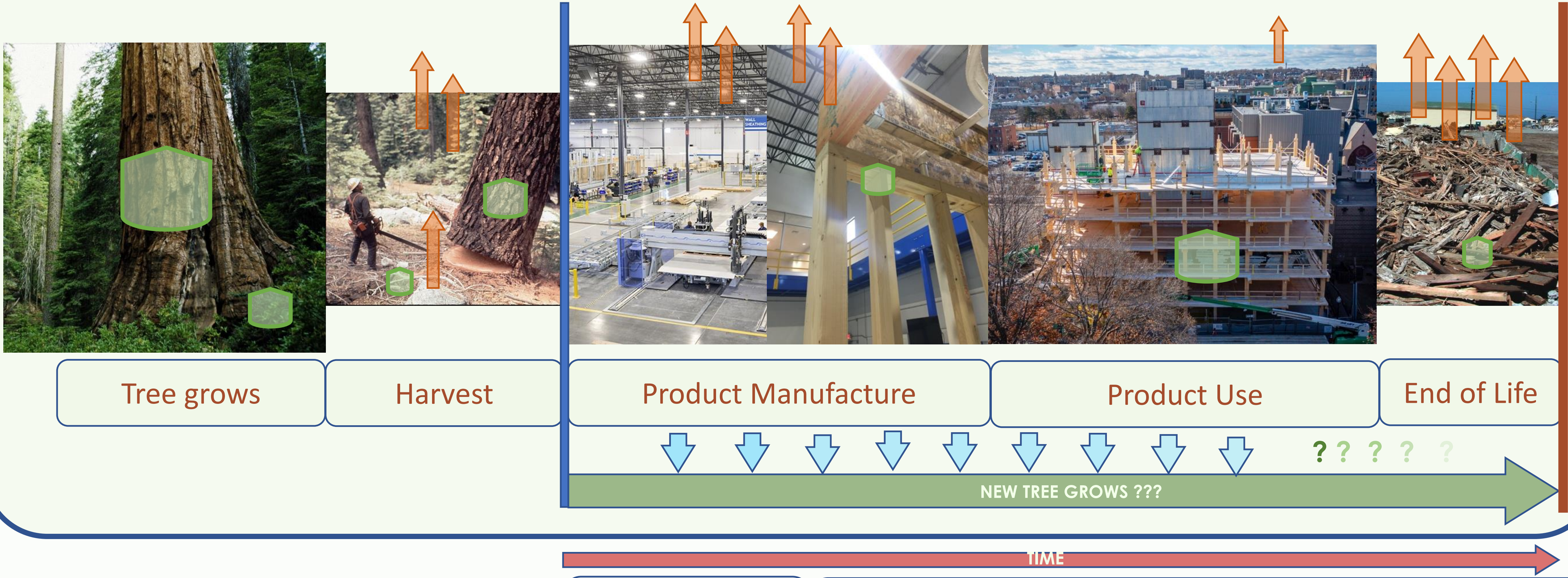
\+ Aligned with Cradle to Gave LCA.

\- Clear cut forest wood can be called carbon neutral.

ADAPTED FROM CLF SEMINAR PRESENTATIONS BY REID MINER, RETIRED NCASI

APPROACHES FOR **CARBON ACCOUNTING**

APPROACH 2: CO_2 is removed from atmosphere by tree replacing the harvested tree



Start accounting at harvest

- ? Depends on time horizon + growth rate of new tree.
- New tree is not connected in product material or energy flows
- Does account for deforestation

APPROACHES FOR **CARBON ACCOUNTING**

APPROACH 4: Compares net Carbon removals from “supply area” over “period of interest” .

Ongoing Harvest

Product Manufacture

Product Use

End of Life

TIME

One years harvest

Modeling of alternate scenario to evaluate carbon cost of removal.

ADAPTED FROM CLF SEMINAR PRESENTATIONS BY REID MINER, RETIRED NCASI

APPROACHES FOR **CARBON ACCOUNTING**

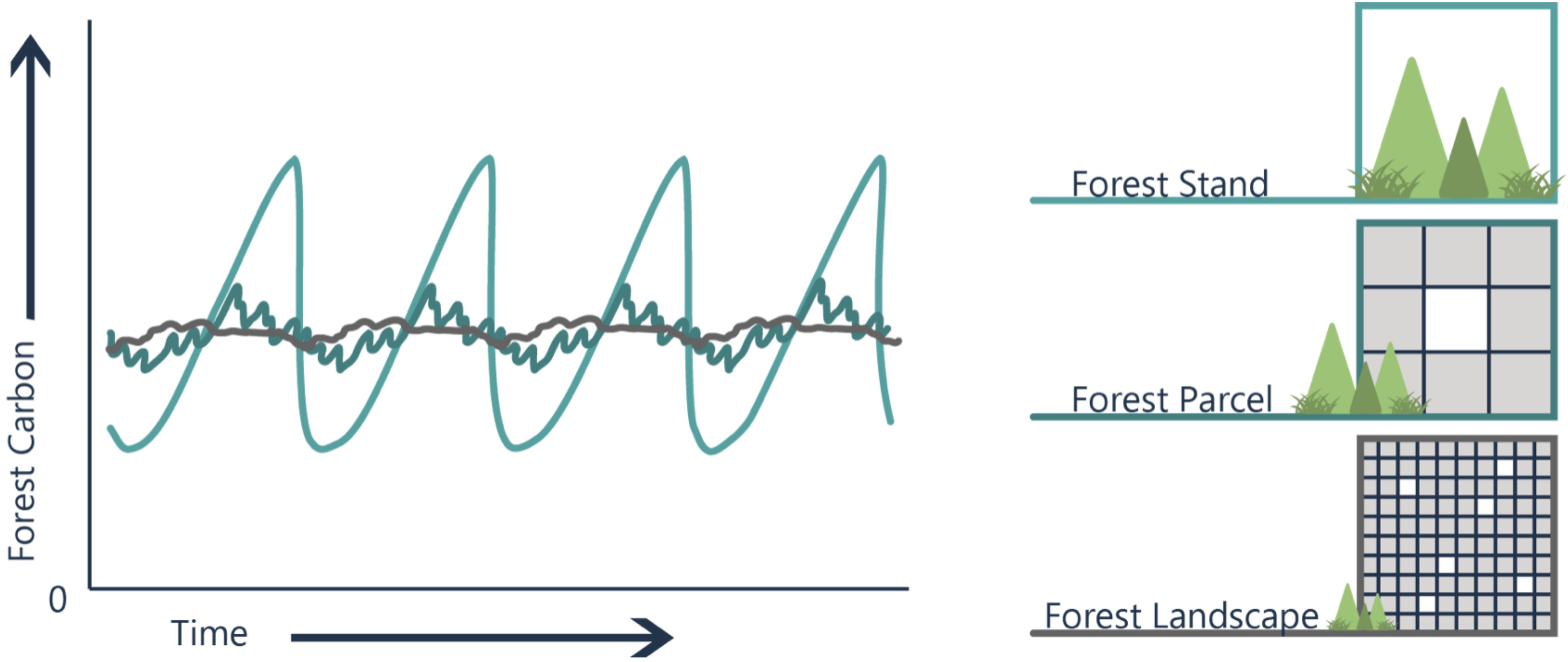
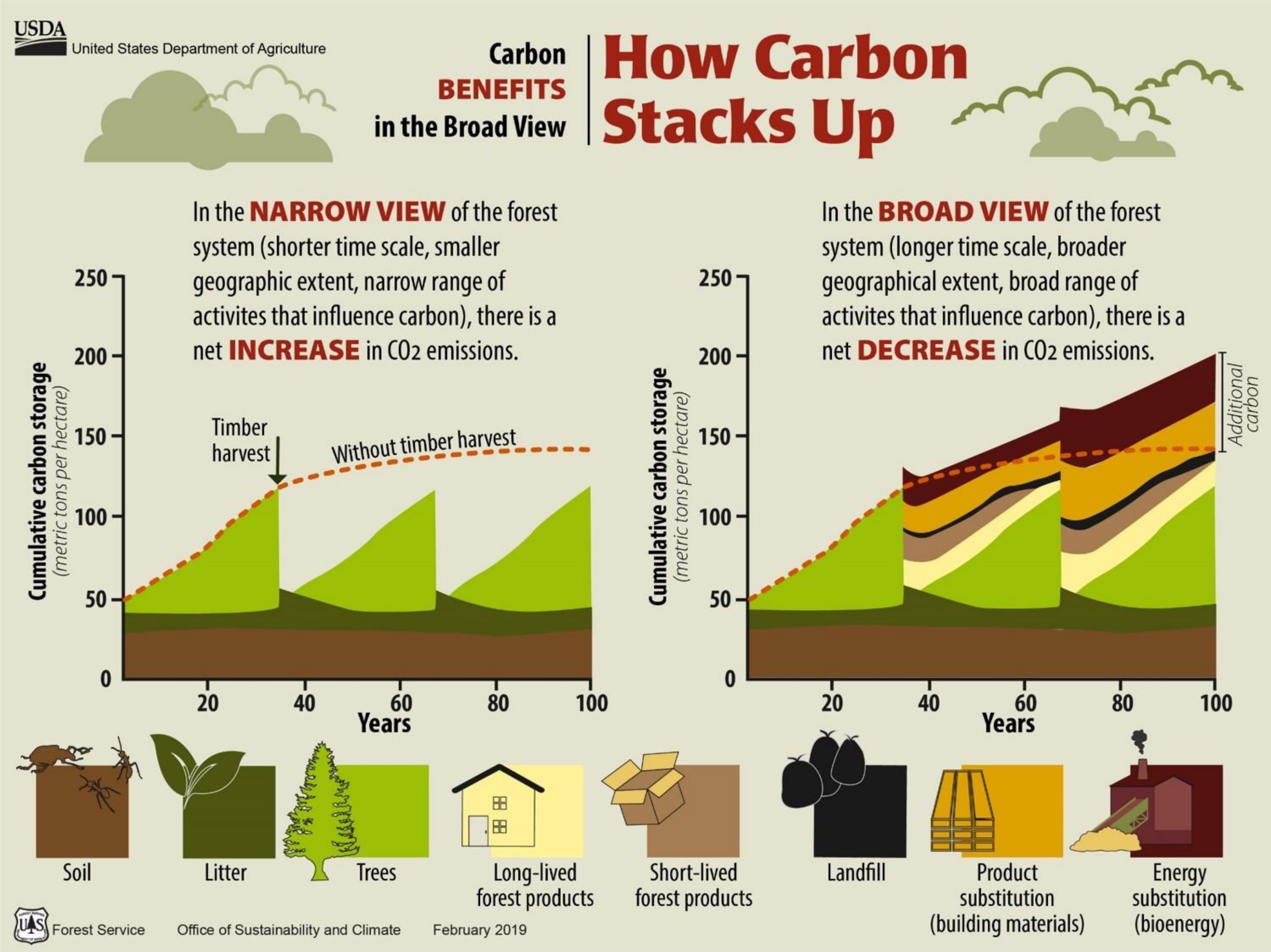


Figure: The influence of spatial and temporal scales on forest carbon storage. Modified from Bowyer et al. (7) and McKinley et al. (5).

APPROACHES FOR **CARBON ACCOUNTING**



FOREST STOCKS ARE CYCLACLE **BUT STORED CARBON CAN MAKE THE CYCLE ADDITIVE**

APPROACHES FOR **CARBON ACCOUNTING**

CONFUSED? DO WE HAVE TIME TO FIGURE THIS OUT?

THE BENEFIT OF **RAPID GROWTH CYCLE** MATERIALS

STORES CARBON THIS YEAR (!!) AND BUILDS SOIL

ENOUGH HAS TO BE ENOUGH !!

THE PATH TO ZERO:

- Stabilize population at 7.5 Billion
  - 2 children per couple with perfect birth control
- Reduce industrial output
  - "enough" material wealth at 10% higher than 2000 levels "for all"
    - reduction for the rich
    - increase for the poor
- Technological increase
  - Abate pollution
  - Increase land yields
  - Protect renewable resources from erosion

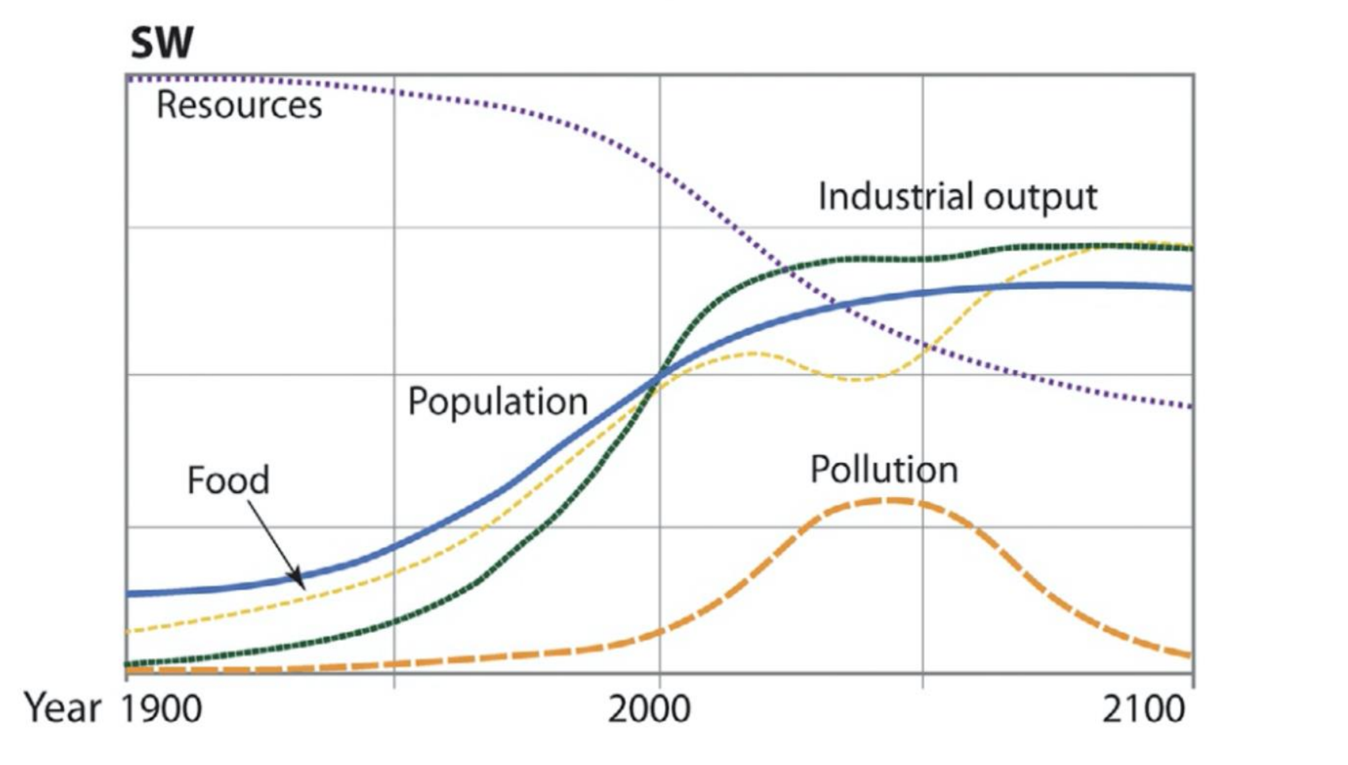


FIGURE 1 The BAU, BAU2, CT, and SW scenarios. Adapted from *Limits to Growth: The 30-Year Update* (p. 169, 173, 219, 245), by Meadows, D. H., Meadows, D. L., and Randers, J., 2004. Chelsea Green Publishing Co. Copyright 2004 by Dennis Meadows. Adapted with permission

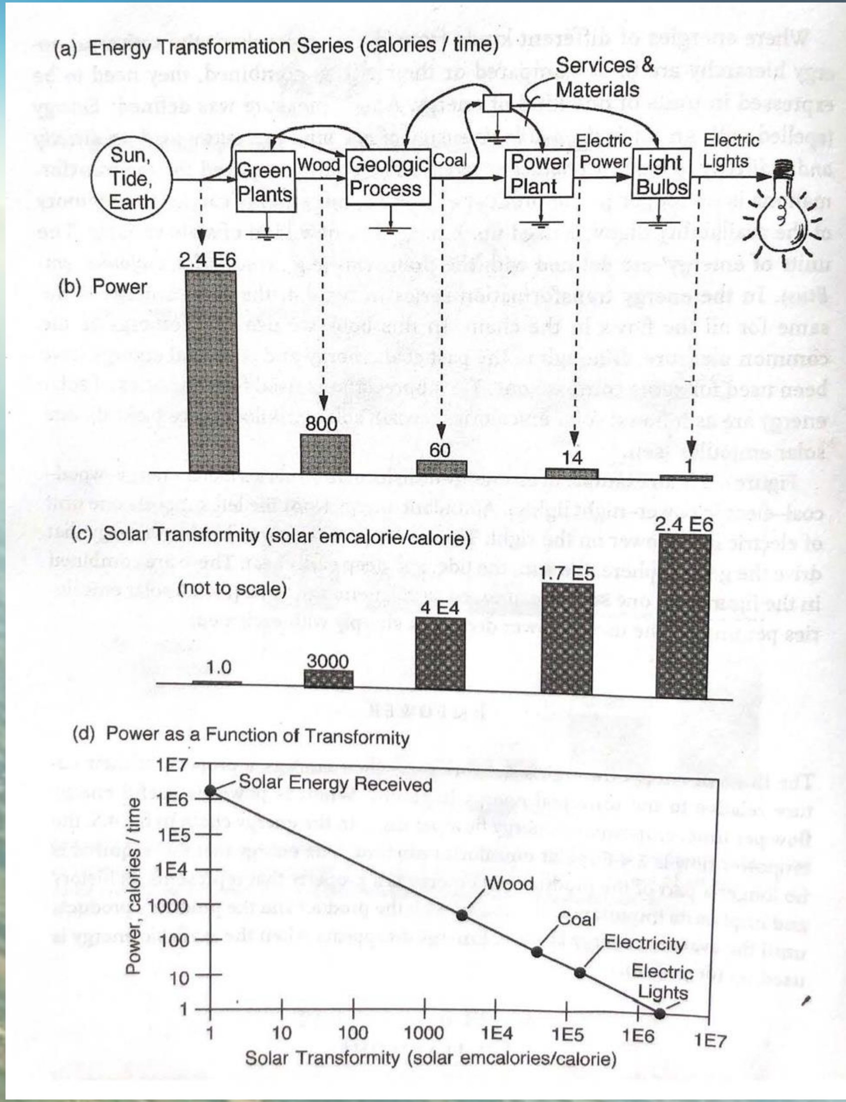
THE PATH TO ZERO

STACKING FUNCTIONS
COMPLEMENTARITY
TRANSFORMABILITY

MULTIFUNCTIONAL SOLUTIONS

- Reduce loads:
  - Passive house, ultra low flow fixtures, DWHR, etc.
- *Solving a single problem with technology will never be net positive.*
- *Natures' Multifunctional Systems are net positive*
  - *look to them for inspiration.*
- *Use "waste" outputs as inputs*
- *Systems that use water like hydronics or geothermal can have functions added to them much easier.*
- *Make the next generation of systems plug-and-play like VRF but add new stacked functions*

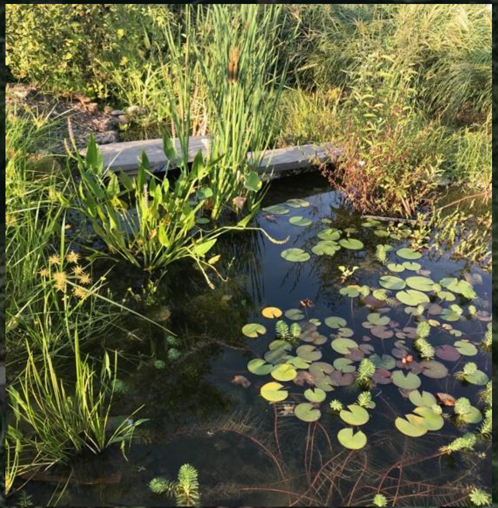
THE SECOND LAW OF THERMODYNAMICS AND THE PATH TO ZERO



LOW TECH IS THE TRUE HIGH TECH – PRIORITIZE PASSIVE + NATURAL SYSTEMS

THINK LIKE NATURE

+ REDUCE, CAPTURE, STORE, **ENERGY** IN ALL FORMS



STACKING FUNCTIONS
COMPLEMENTARITY
WASTE AS NUTRIENT

THINK LIKE NATURE

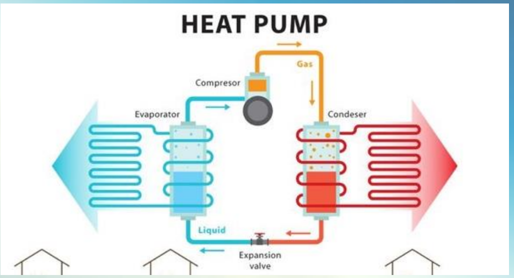
ENERGY TRANSFORMABILITY

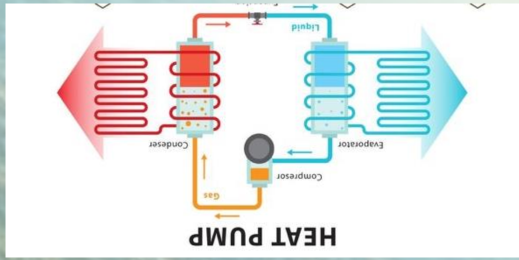
THINK LIKE NATURE ?

ENERGY TRANSFORMABILITY

THINK LIKE NATURE + A DOSE OF TECHNOLOGY

ENERGY TRANSFORMABILITY





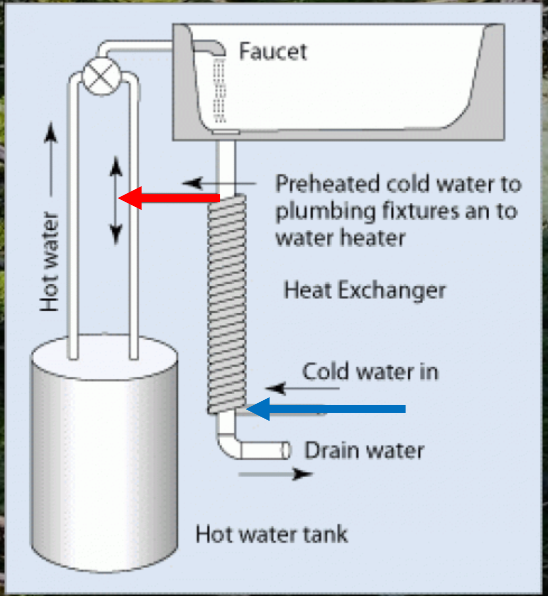
THINK LIKE NATURE

COMPLEMENTARY LOADS
. . .PRETTY CRUDE EXAMPLE

THINK LIKE NATURE

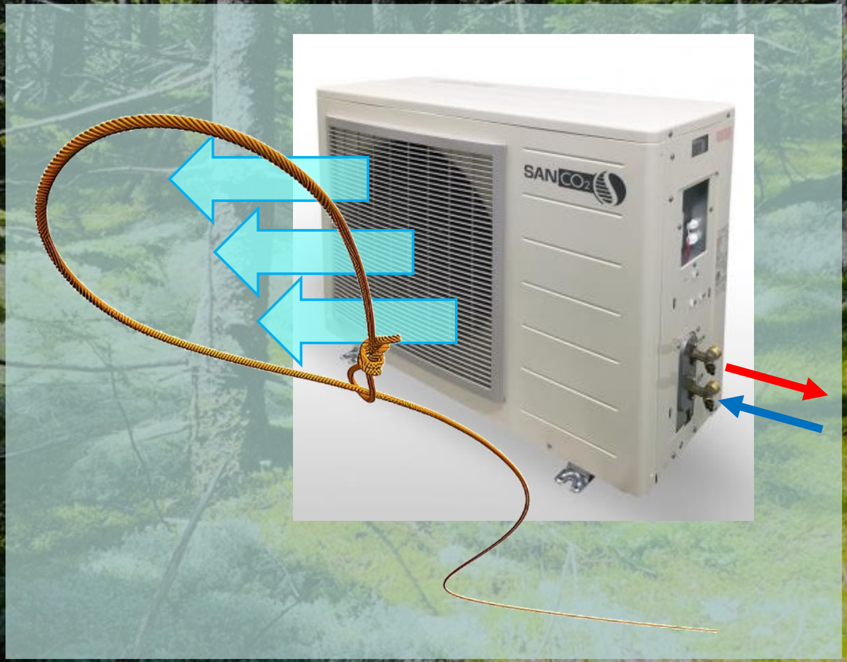
DIVERSE ABUNDANCE, WITHIN AVAILABLE ENERGY LIMITS, NO WASTE

Drain Water Heat Recovery



* Why have we forgotten about these? they are so simple!

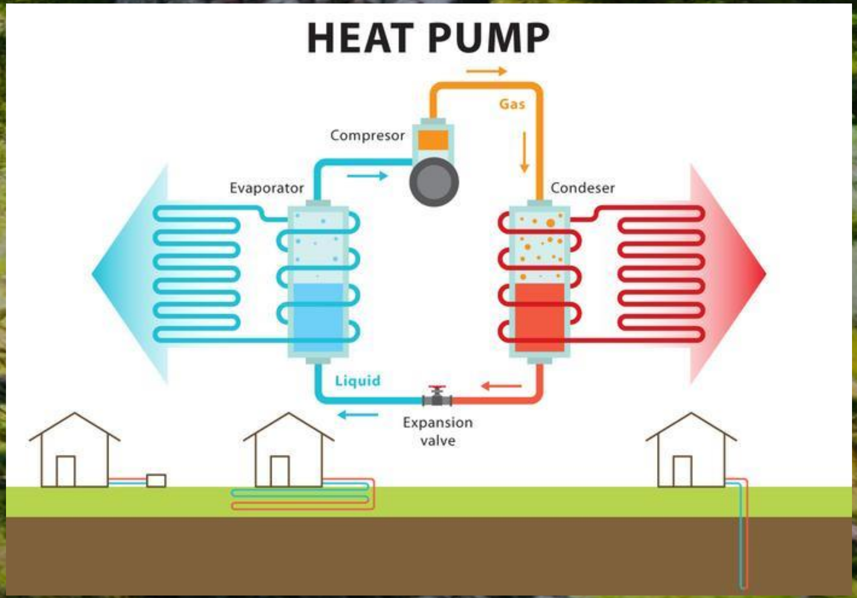
Desiccant Dehumidification? Adsorption Chillers?



Use the wasted cooling from CO2 Hot Water Heat Pumps

* Use all that cooling energy that is thrown away by heat pump hot water heaters

Water-to-water heat pumps used to change "waste" energy into useable energy by "lifting" to useable temperatures

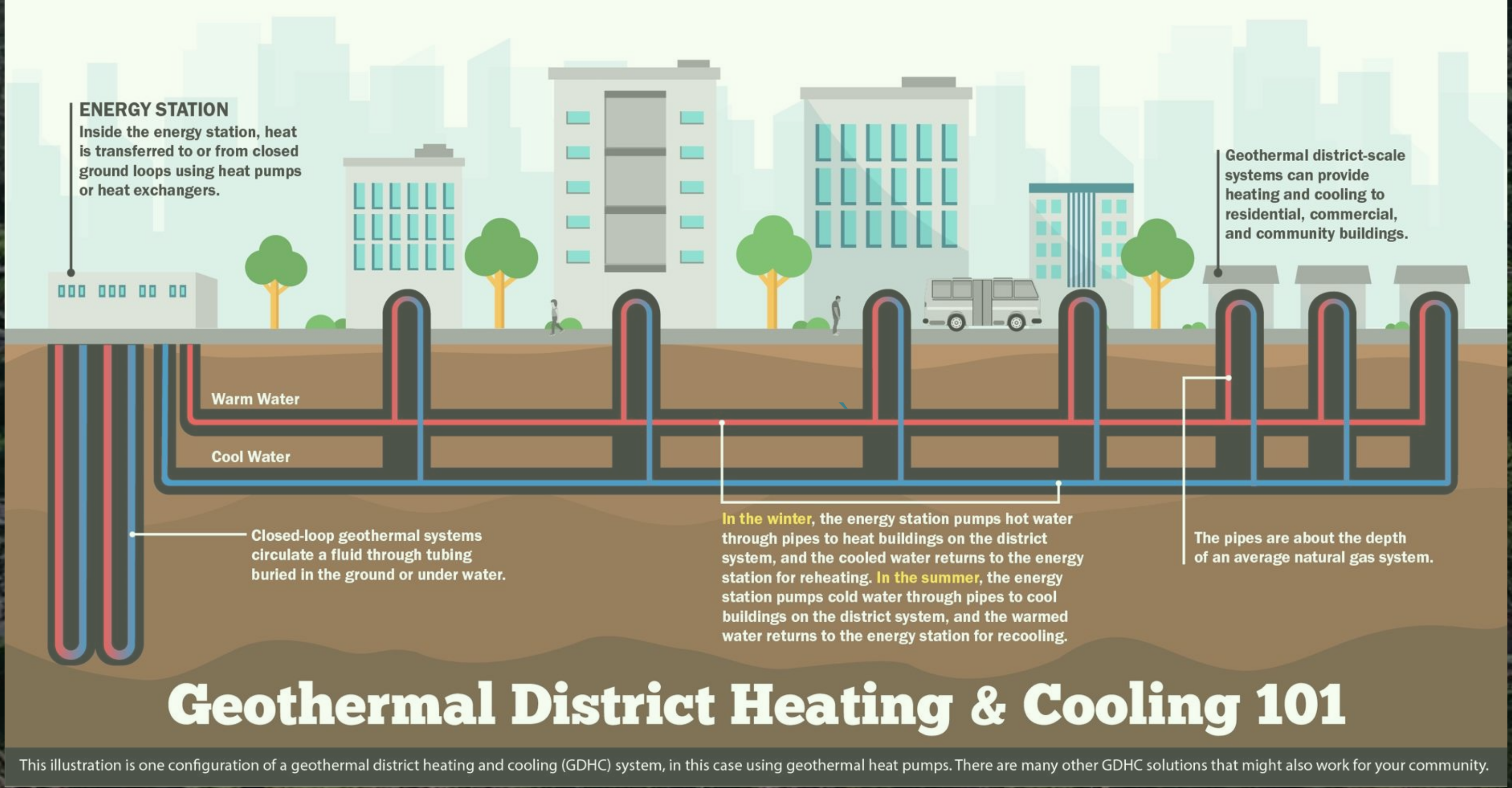


* Similar in concept to geothermal, but a ground loop isn't necessarily required.

EXISTING COMPLIMENTARY SOLUTIONS THAT NEED MORE ATTENTION

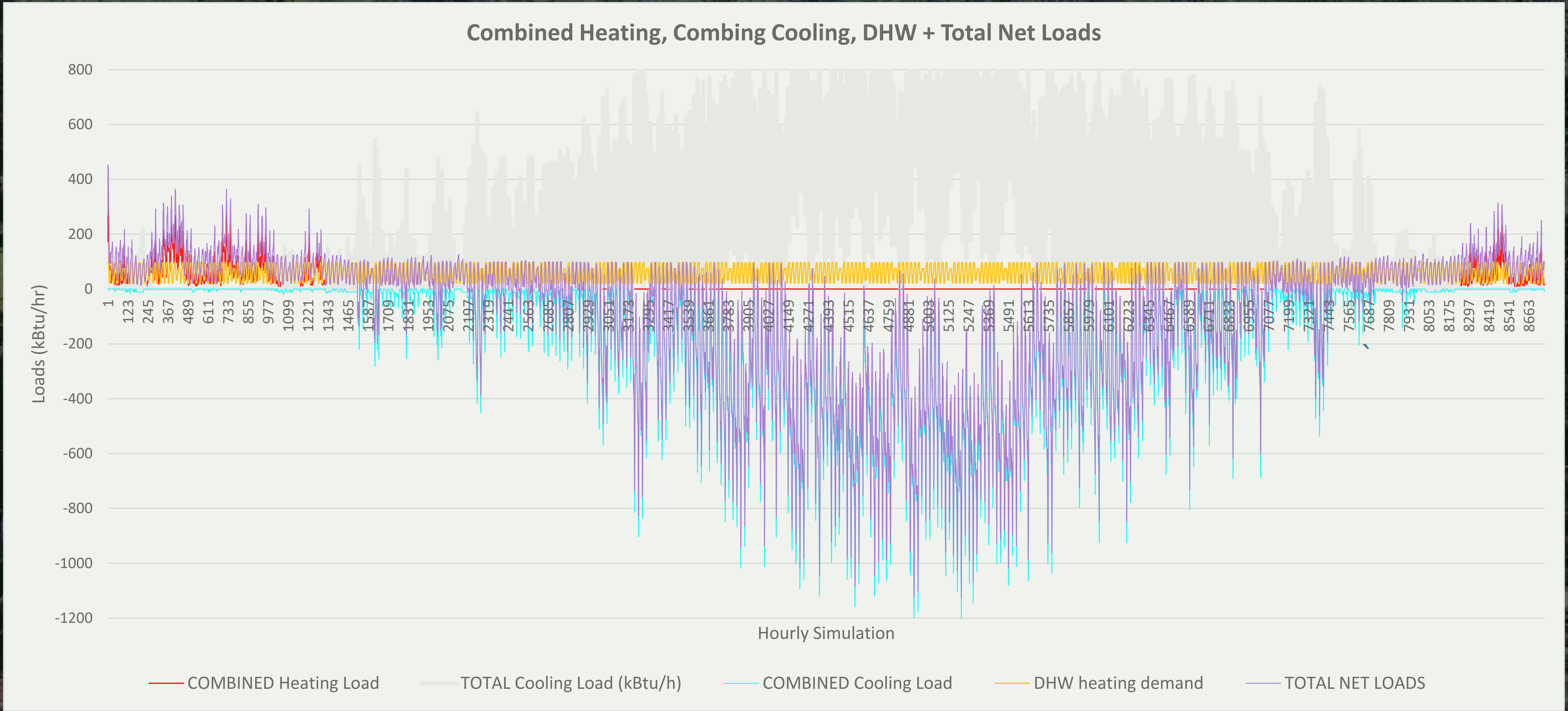
THINK LIKE NATURE

STACKING FUNCTIONS
COMPLEMENTARITY
WASTE AS NUTRIENT



THINK LIKE NATURE

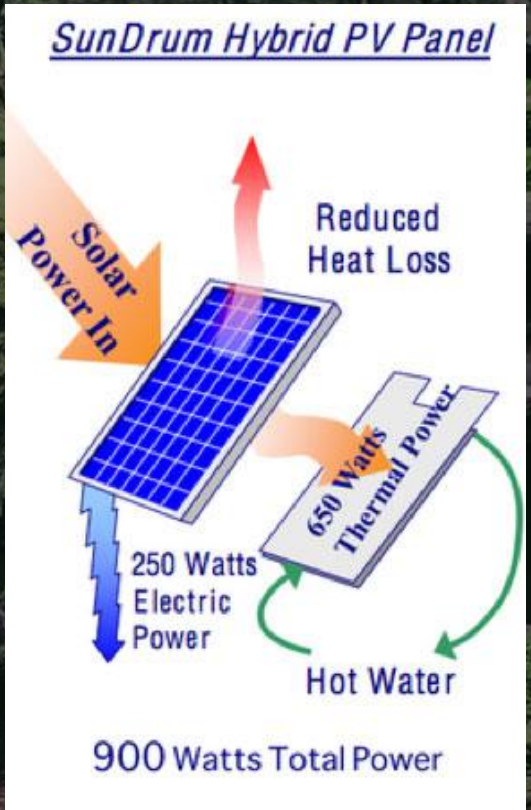
STACKING FUNCTIONS
COMPLEMENTARITY
WASTE AS NUTRIENT



THINK LIKE NATURE

DIVERSE ABUNDANCE, WITHIN AVAILABLE ENERGY LIMITS, NO WASTE

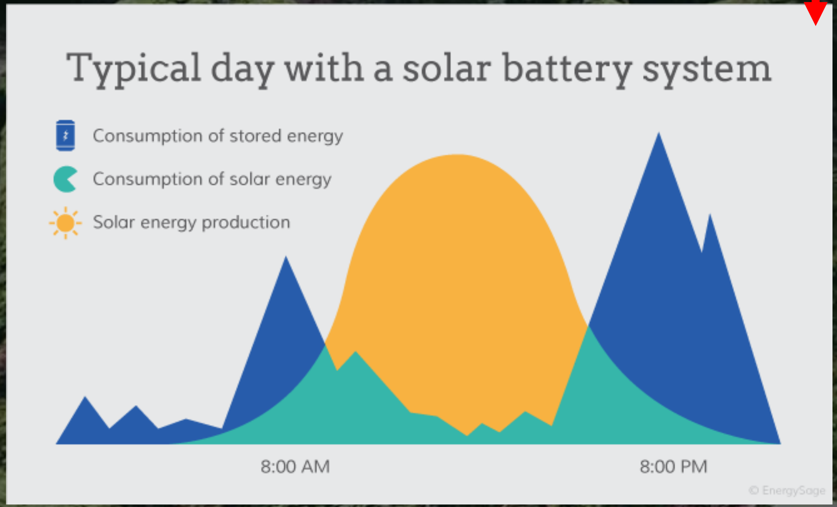
Stacked Photovoltaic & Solar Hot Water Systems



* This type of low temperature collector opens all kinds of hydronic possibilities without flash and freeze issues

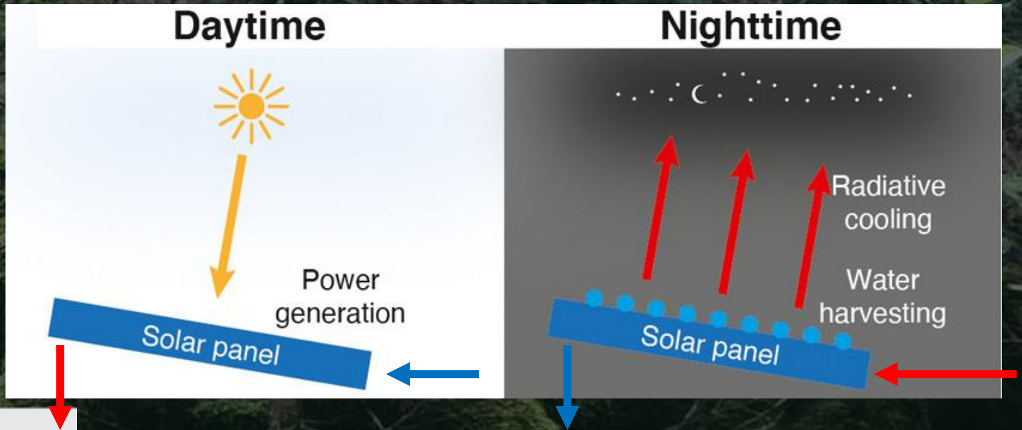
Thermal Storage

- ***Grid Storage (Solar time-shift)***
- ***Heat Recovery time-shift***
- ***Equipment Size reduction***



* Storage isn't just about renewable grid integration, but can enable other time-delay heat recovery options, such as…

Night Sky Radiant Cooling



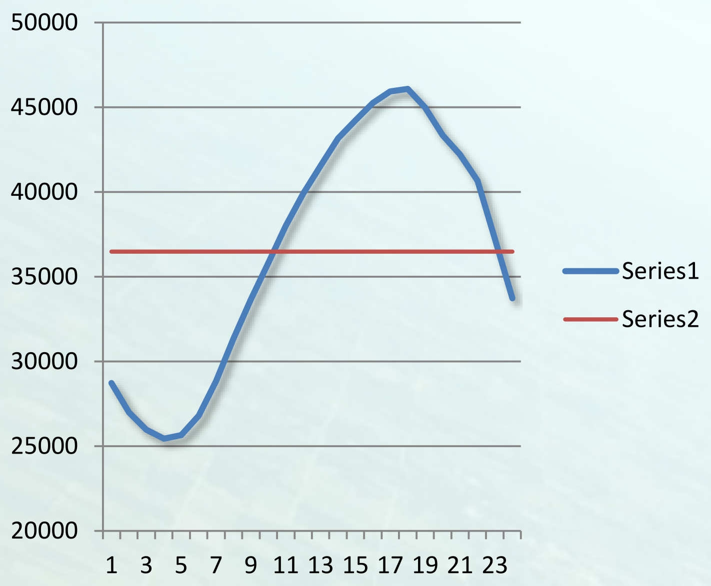
* Cool the planet with solar thermal panels by launching heat into space ?!

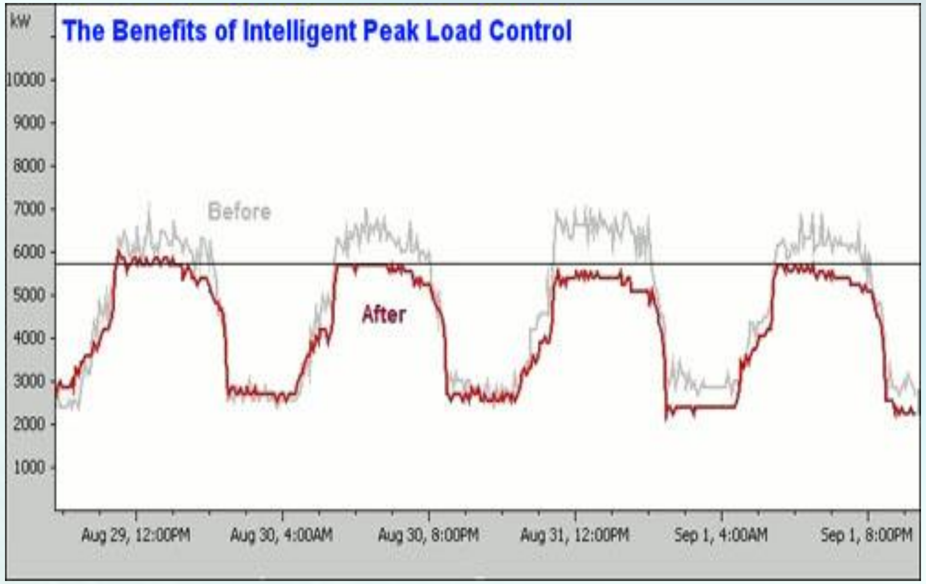
Phase Change Materials?

STACKING FUNCTIONS
COMPLEMENTARITY
TRANSFORMITY

THINK LIKE NATURE

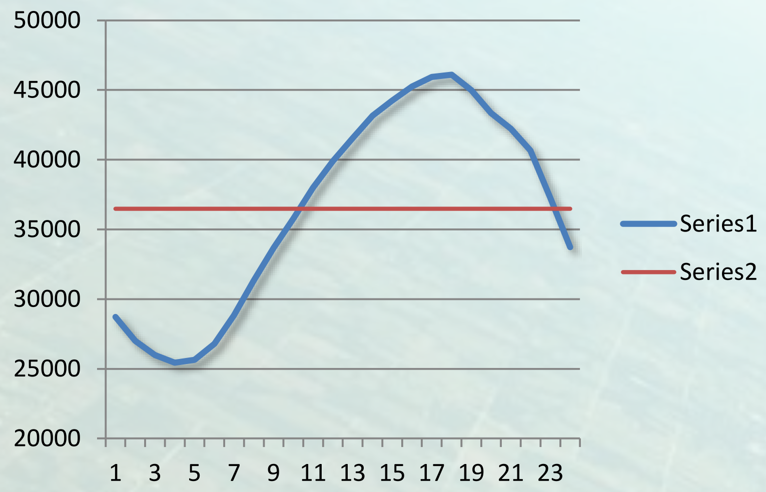
STORAGE TIME SHIFTING





THINK LIKE NATURE

STORAGE TIME SHIFTING



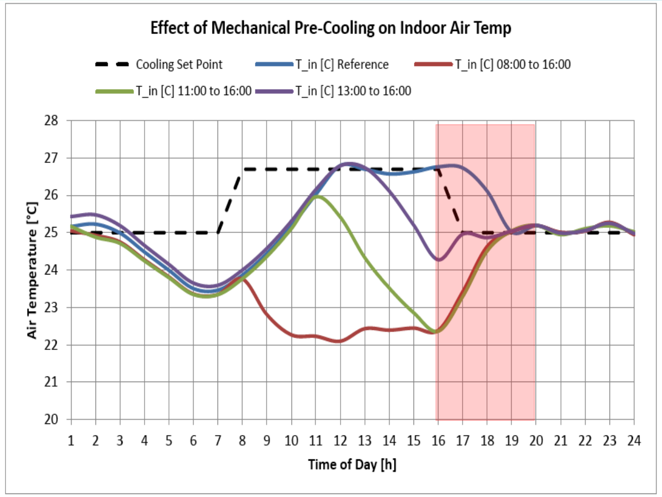
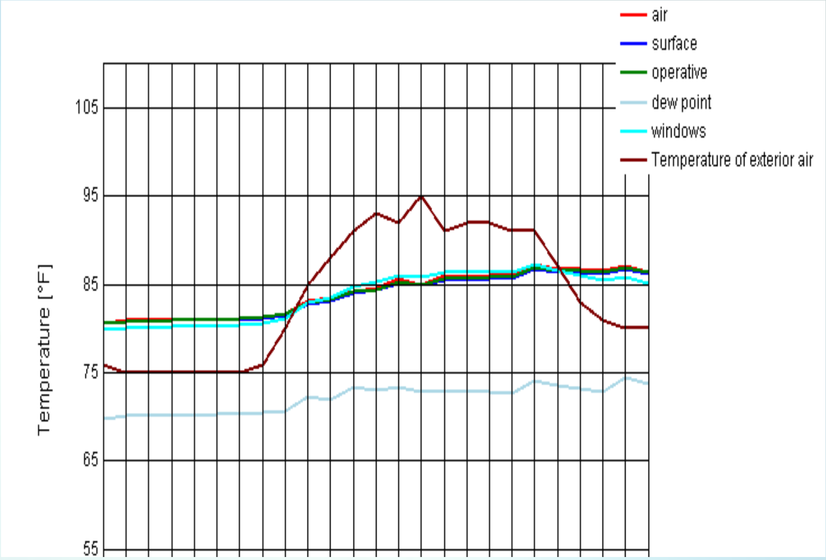


Figure 3: Effect on indoor air temperature of changing the cooling set points at different times to produce pre-cooling. 22.2°C or 72°F set point used, climate zone 3B – El Paso, TX. The dashed line shows the standard (no pre-cooling) cooling set point temperatures throughout the day. The red box indicates the peak period.



THE PATH TO ZERO

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STAENGL ENGINEERING

Passive to POSITIVE
PASSIVE HOUSE AND LOW IMPACT DESIGN