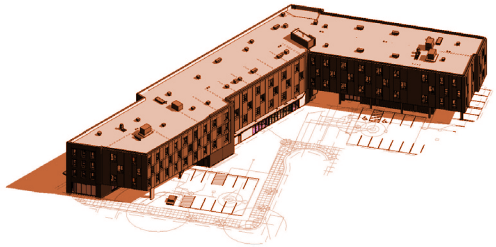

NET ZERO
FELLOWSHIP
RESEARCH EVENT
HANNAH RUSNAC
HOLST ARCHITECTURE
Building photo by Christian Columbres

Thank you!

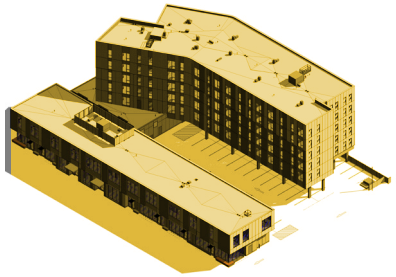
HOLST

CARBON CROSSROADS: AN ANALYSIS OF OPERATIONAL & EMBODIED CARBON IN MULTIFAMILY HOUSING

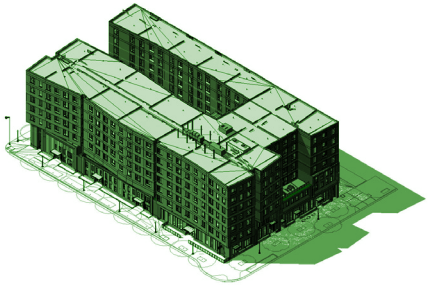
2023 ENERGY TRUST OF OREGON RESEARCH FELLOWSHIP



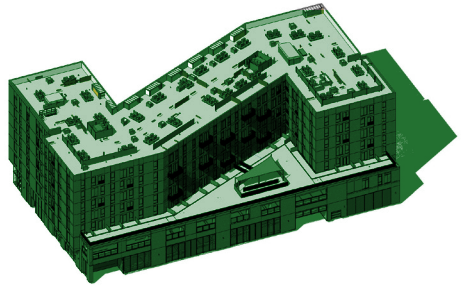
72FOSTER



THE NICK FISH

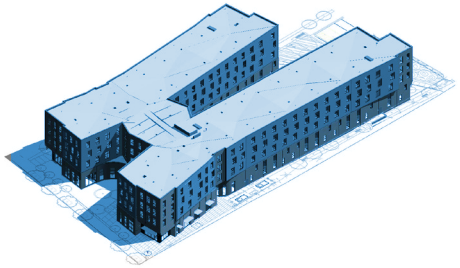


THE FOWLER

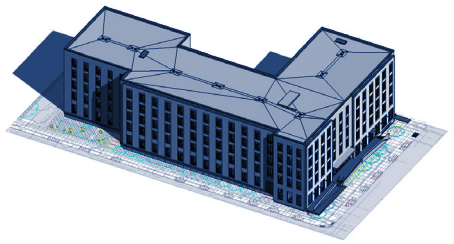


HEARTH

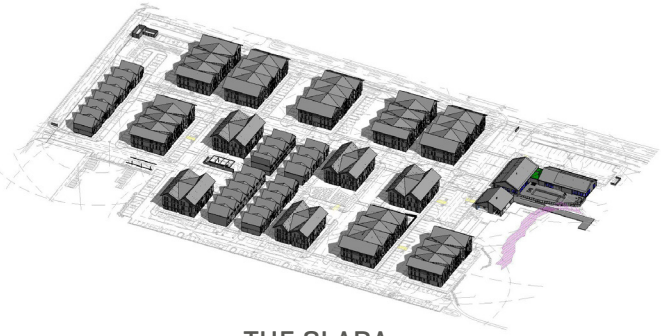
ARGYLE GARDENS



3000 POWELL



THE AURORA



THE CLARA

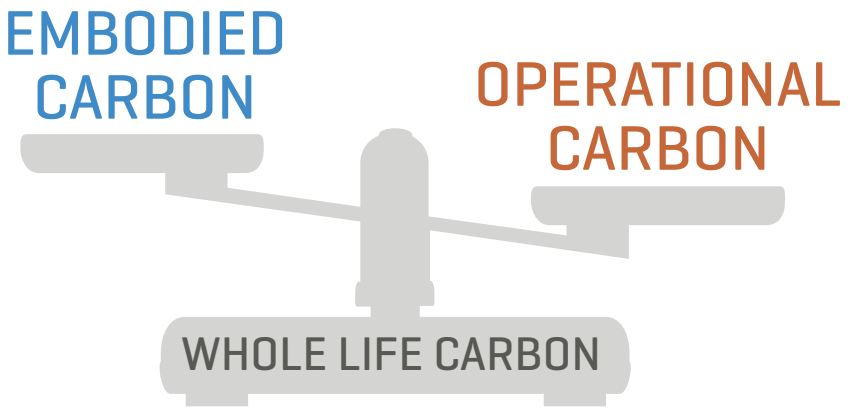
RESEARCH OVERVIEW

This Energy Trust of Oregon research project analyzes the operational, embodied, and whole life carbon of eight multifamily buildings in the Pacific Northwest.

PRIMARY RESEARCH GOALS

1) Provide public operational and embodied carbon data, especially for low and mid-rise wood frame multifamily construction in Oregon.

2) Determine the predicted life-span balance between operational carbon and embodied carbon, for eight multifamily projects in Oregon.



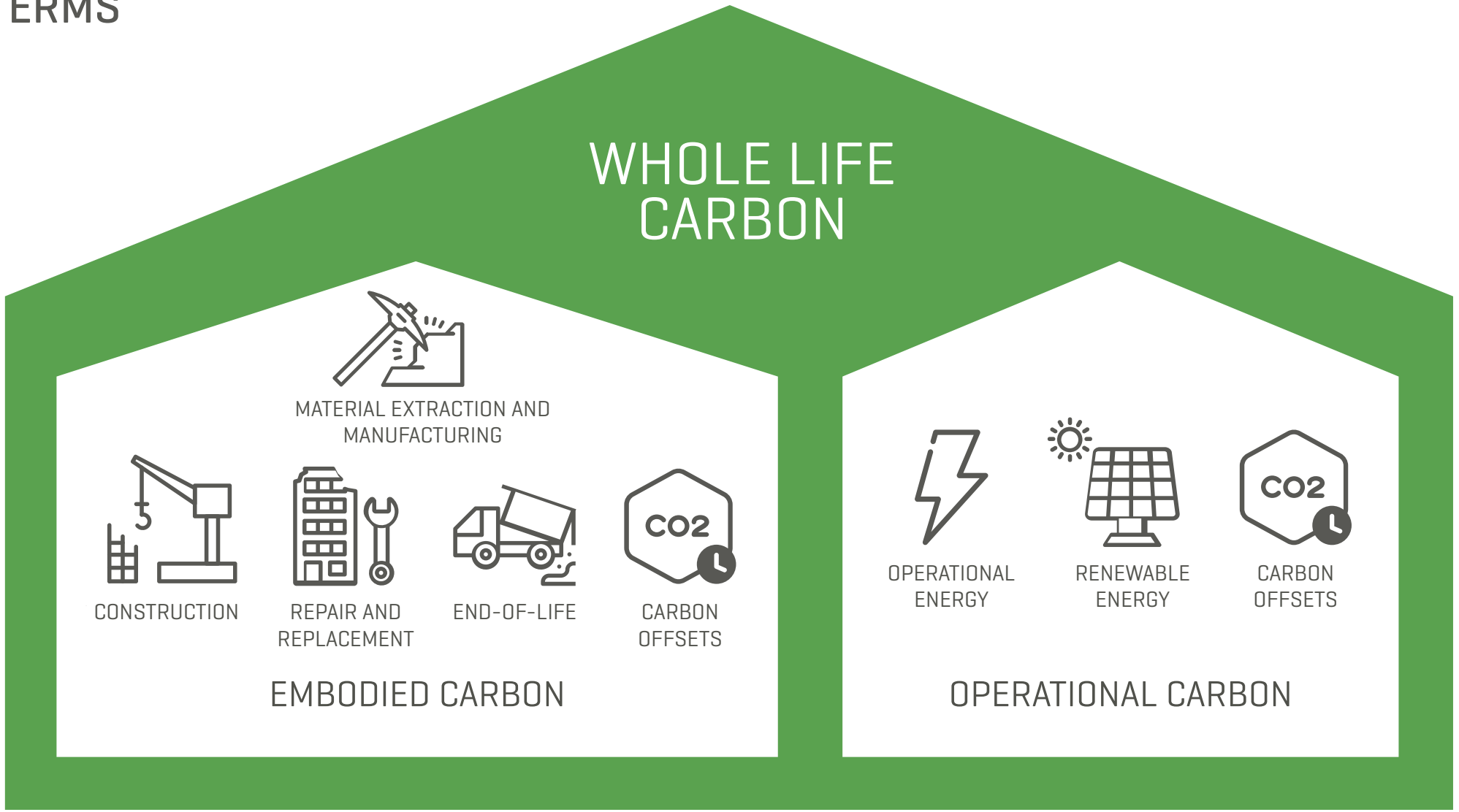
ACKNOWLEDGEMENTS

This research would not be possible without the gracious permission of the various building owners. Not only did they allow for the study of their buildings, but they also contributed their efforts in acquiring the energy use data for the project.

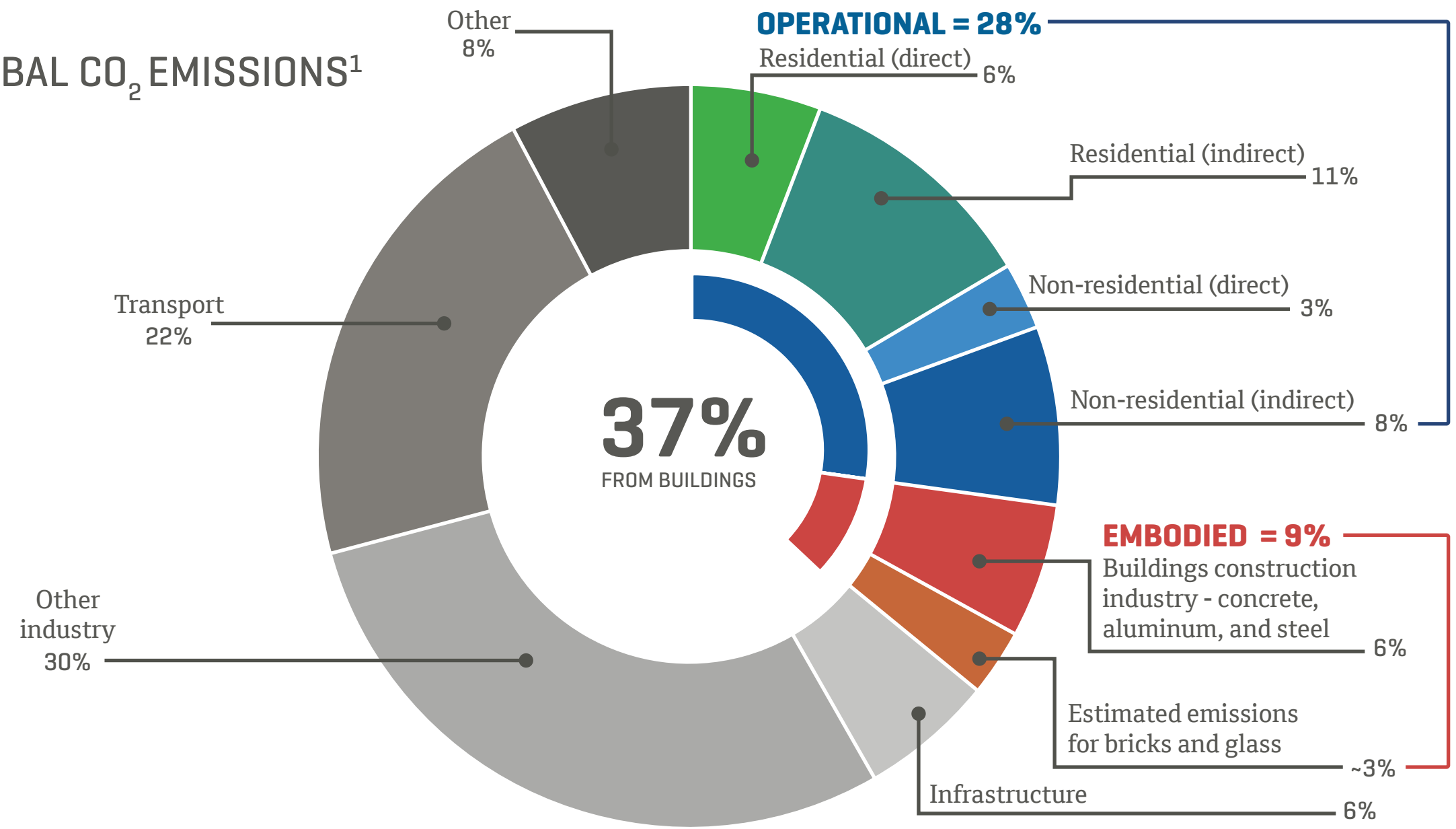
- Roundhouse
- Our Just Future
- Transition Projects
- Home Forward
- REACH CDC


ARGYLE GARDENS

KEY TERMS



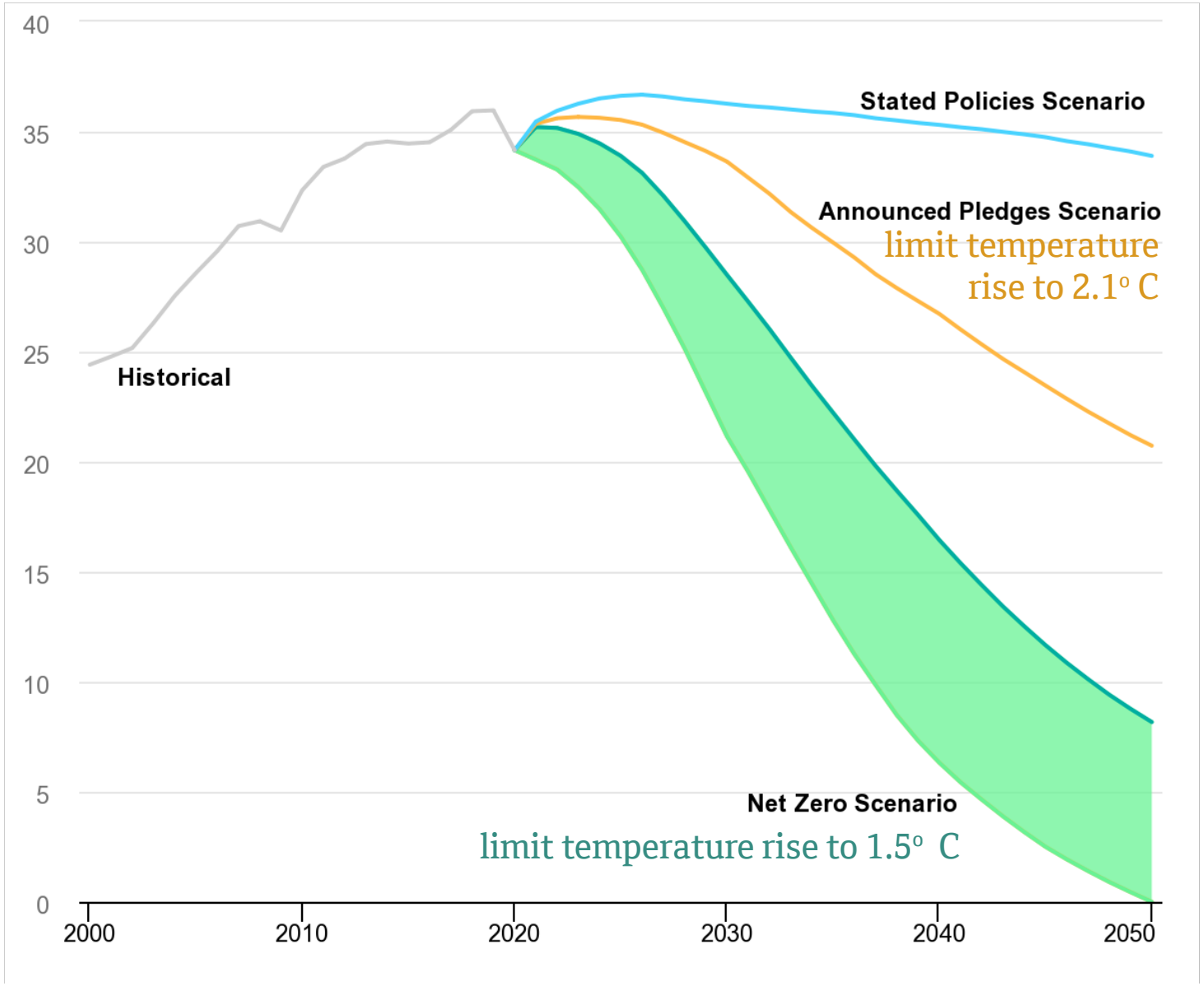
GLOBAL CO_2 EMISSIONS[1]



1 United Nations Environment Programme. 2022. *2022 Global Status Report for Buildings and Construction*, https://www.unep.org/resources/publication/2022-global-status-report-buildings-and-construction, data from International Energy Agency. 2022. *Tracking Buildings 2022*. Paris: International Energy Agency. Available at: https://www.iea.org/reports/tracking-buildings-2021

CO_2 EMISSIONS IN DIFFERENT SCENARIOS, 2000-2050[1]

In order to reduce global temperature rise to 1.5° C, the world must achieve net-zero energy related and industrial process CO_2 emissions by 2050. Current climate pledges , without additional action, are consistent with a 2.1° C temperature rise in 2100.

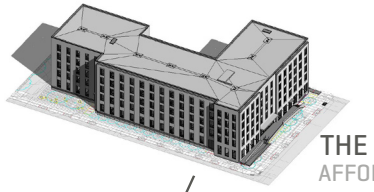


1 IEA. 2021. Net Zero by 2050, IEA: Paris https://www.iea.org/reports/net-zero-by-2050, License: CC BY 4.0

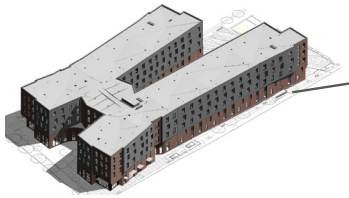
INTRODUCTION TO PROJECTS

CLIMATE AND LOCATION

ARGYLE GARDENS
PERMANENT SUPPORTIVE HOUSING

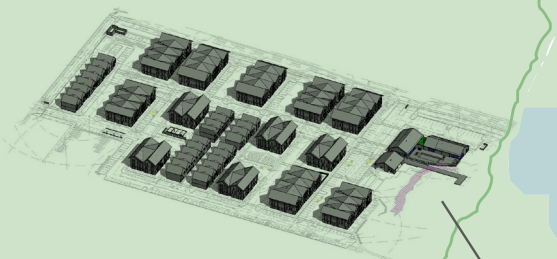


THE AURORA
AFFORDABLE HOUSING

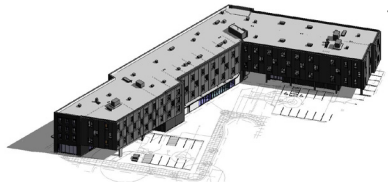


3000 POWELL
AFFORDABLE HOUSING

PORTLAND
5 PROJECTS



THE CLARA
MARKET RATE HOUSING



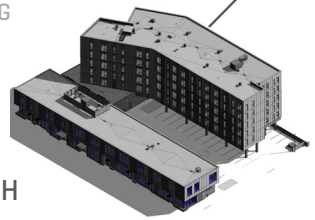
72FOSTER
AFFORDABLE HOUSING

BEND

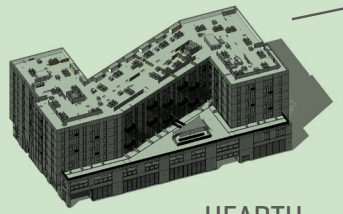
ONTARIO

EAGLE
1 PROJECT

BOISE
2 PROJECTS



THE NICK FISH
AFFORDABLE &
MARKET RATE HOUSING



HEARTH
MARKET RATE HOUSING

THE FOWLER
MARKET RATE HOUSING

MEDFORD

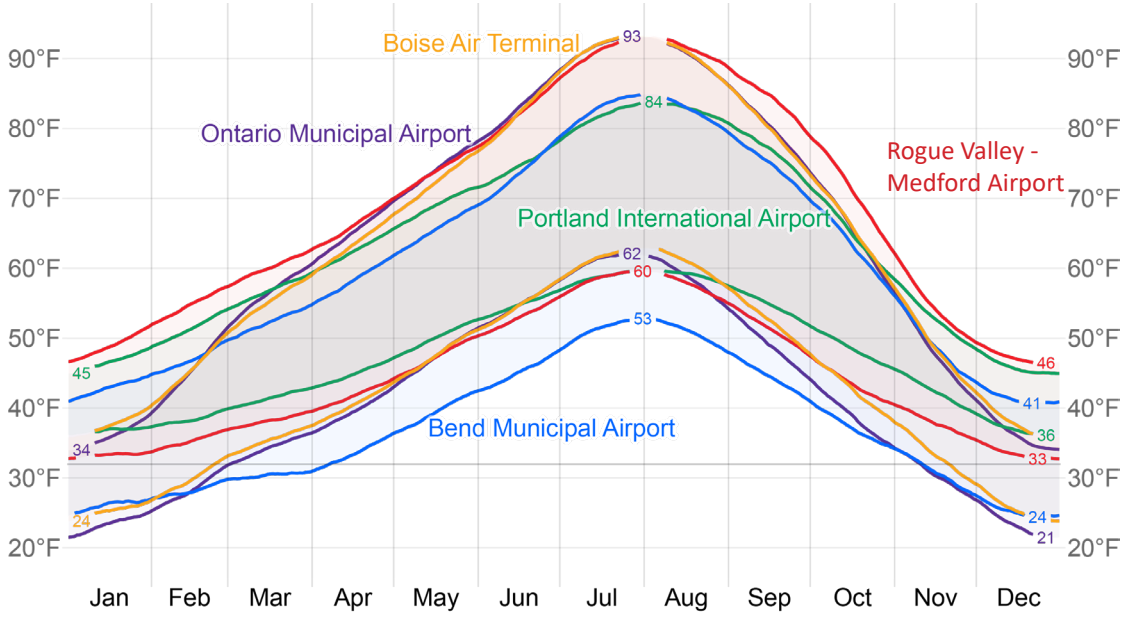
ZONE 4C (MARINE)

ZONE 5B (DRY)

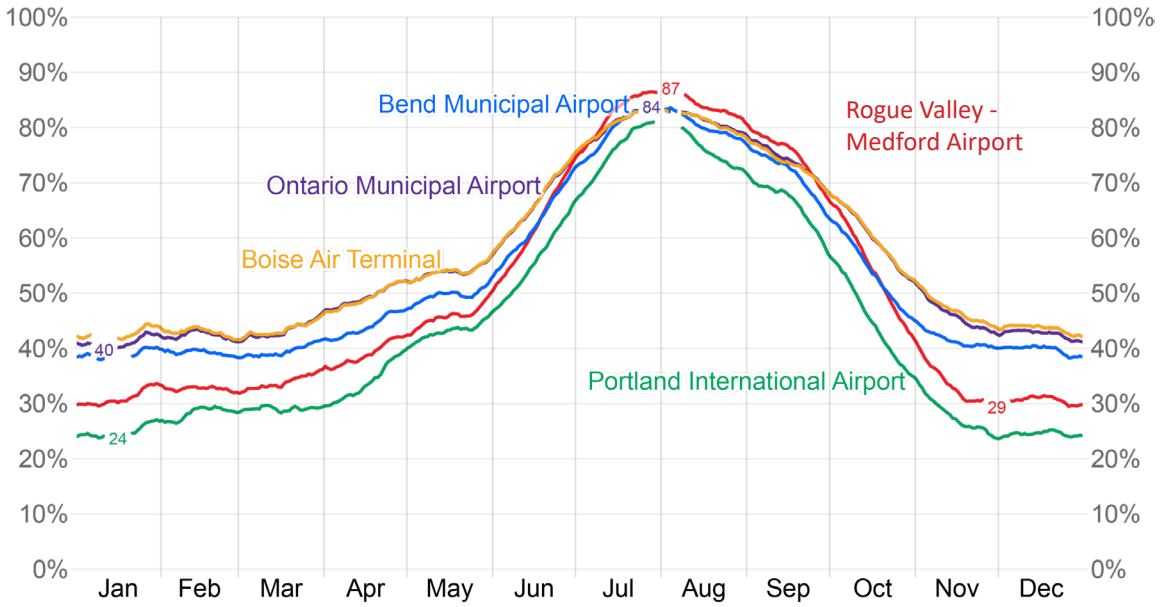
ZONE 6B

CLIMATE & LOCATION

AVERAGE HIGH AND LOW TEMPERATURE



% CHANCE OF CLEAR SKIES

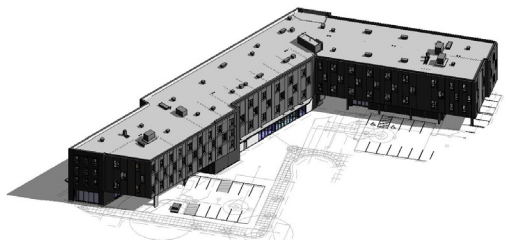


PROJECTS

Portland

72FOSTER (2019)

affordable



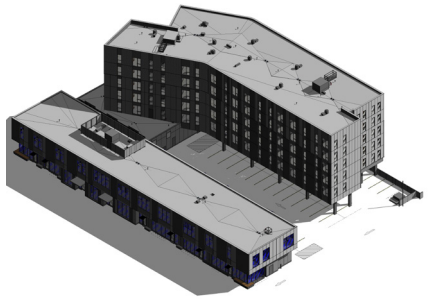
101 UNITS

- RETAIL
- PARKING
- SOLAR PANELS

Portland

THE NICK FISH (2021)

affordable + market-rate



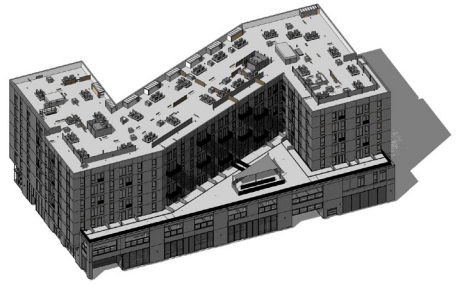
75 UNITS

- OFFICE
- RETAIL
- PARKING
- SOLAR PANELS

Boise

HEARTH (2021)

market-rate



163 UNITS

- RETAIL
- PARKING

Boise

THE FOWLER (2018)

market-rate

163 UNITS

- RETAIL
- PARKING

PROJECTS

Portland

ARGYLE GARDENS (2020)

affordable, permanent supportive

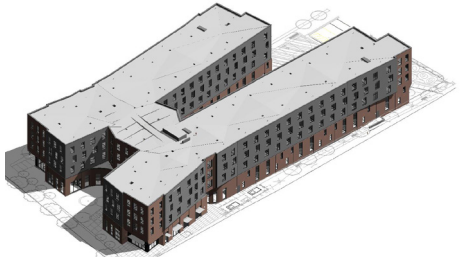
72 UNITS

- SOLAR PANELS
- SRO UNITS

Portland

3000 POWELL (2024)

affordable



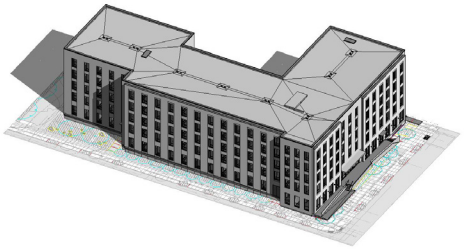
196 UNITS

- NEWER ENERGY CODE

Portland

THE AURORA (2023)

affordable



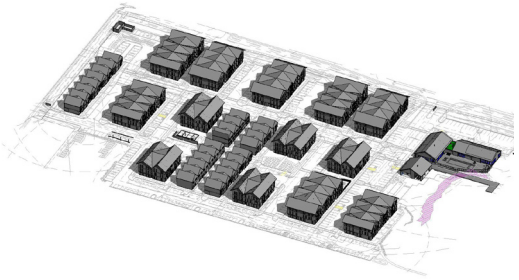
93 UNITS

- ALL ELECTRIC
- SOLAR PANELS

Eagle (Idaho)

THE CLARA (2021)

market-rate



280 UNITS

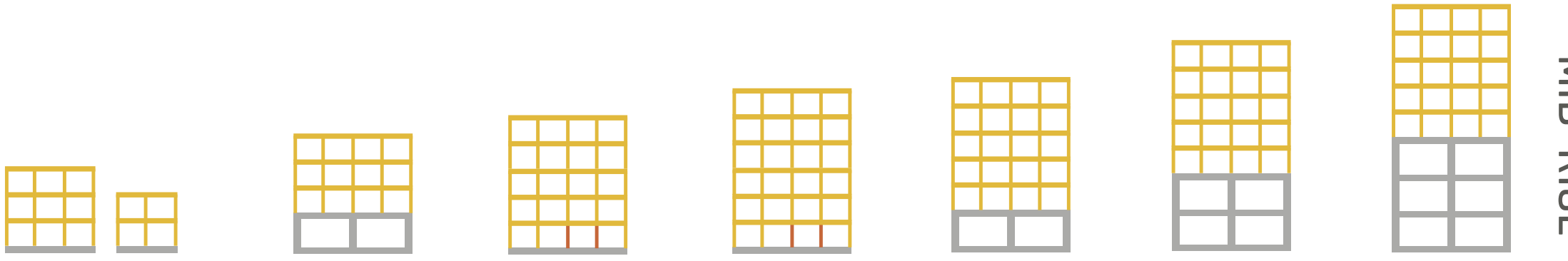
- WALK-UP AND TOWNHOMES

PROJECTS - CONSTRUCTION TYPE + HEIGHT

wood | steel | concrete

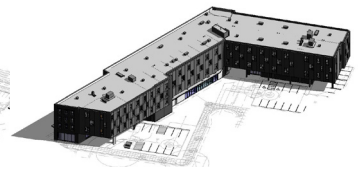
LOW-RISE

MID-RISE



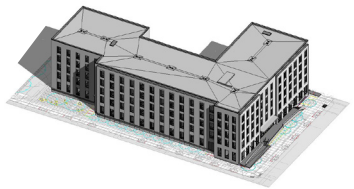
THE CLARA

72FOSTER

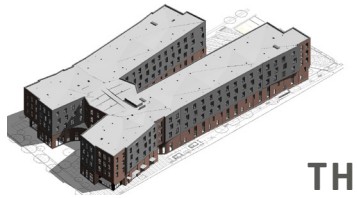


ARGYLE GARDENS

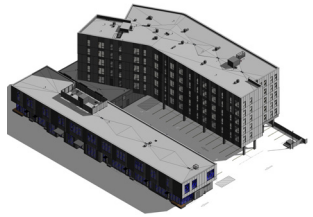
THE AURORA



3000 POWELL

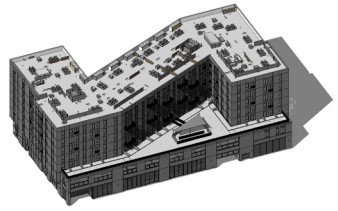


THE NICK FISH



THE FOWLER

THE HEARTH



WHICH PROJECT DO YOU THINK WILL HAVE THE LOWEST WHOLE LIFE CARBON?

A] ARGYLE GARDENS

72 UNITS
- SOLAR
- SRO UNITS

B] HEARTH

163 UNITS
- RETAIL
- PARKING

C] 3000 POWELL

196 UNITS
- NEWER ENERGY CODE

D] THE AURORA

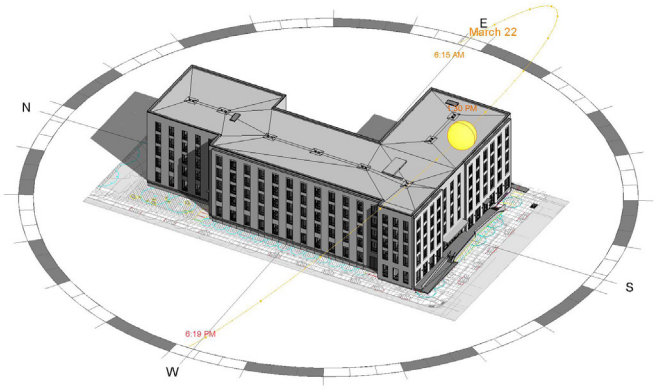
93 UNITS
- ALL ELECTRIC
- SOLAR

OPERATIONAL CARBON

PROCESS

1) REQUEST ELECTRICITY & NATURAL GAS ENERGY USAGE DATA

- Idaho utilities = no aggregate data without tenant release



2) CREATE ENERGY MODELS FOR PROJECTS

- Revit Insight (DOE 2.2 Simulation Engine)
- Limited options for building systems and specifications - not an exact replica

Operational Energy
x Energy Source Carbon Intensity
= Operational Carbon

example:

1 kWh/yr x 10 kgCO_2eq/kWh = 10 kgCO_2eq

3) CONVERT ENERGY USAGE INTO CARBON EMISSIONS

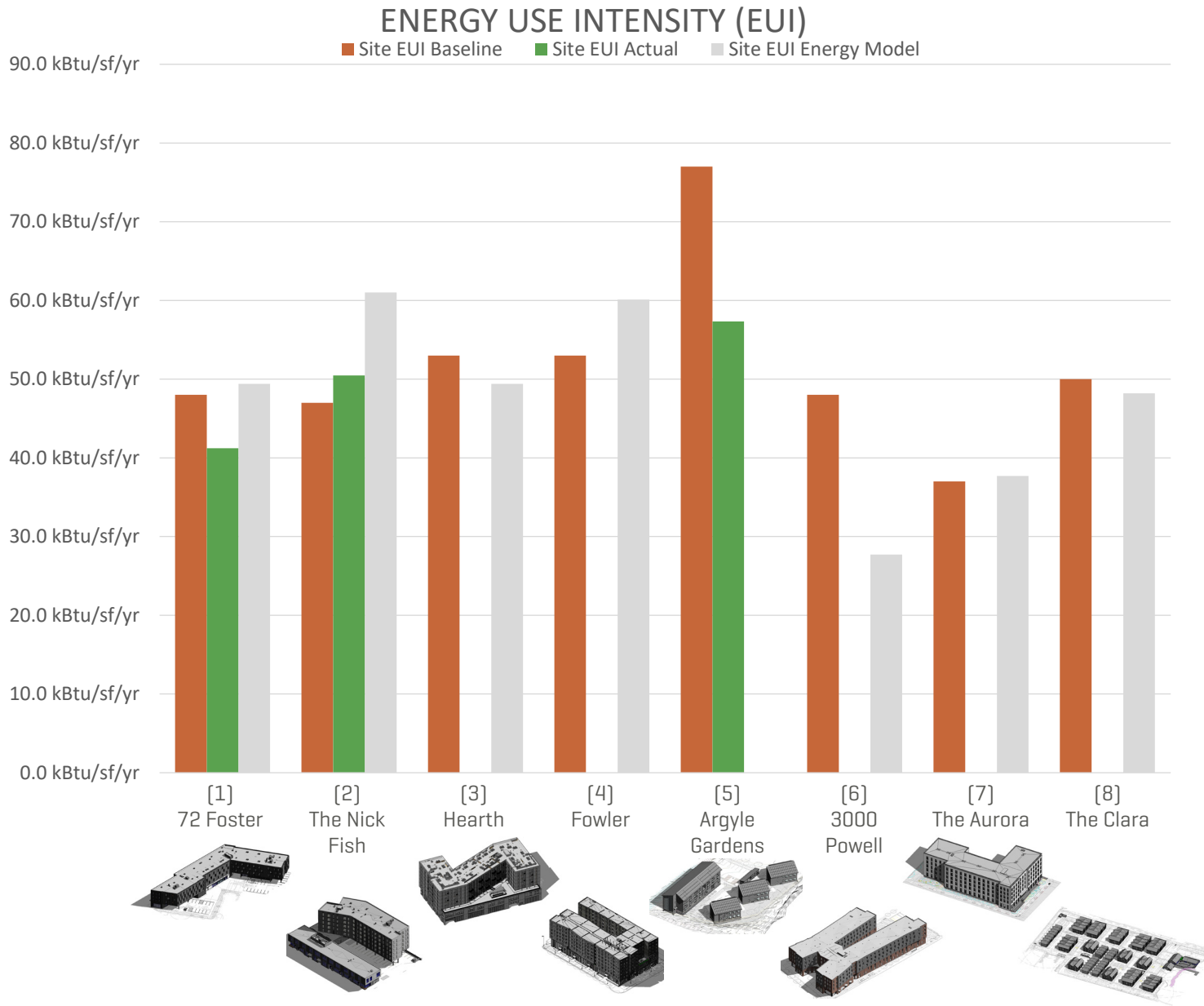
OPERATIONAL CARBON: EUI - ENERGY USE INTENSITY

The overall annual energy consumption in terms of kBtu divided by building area.

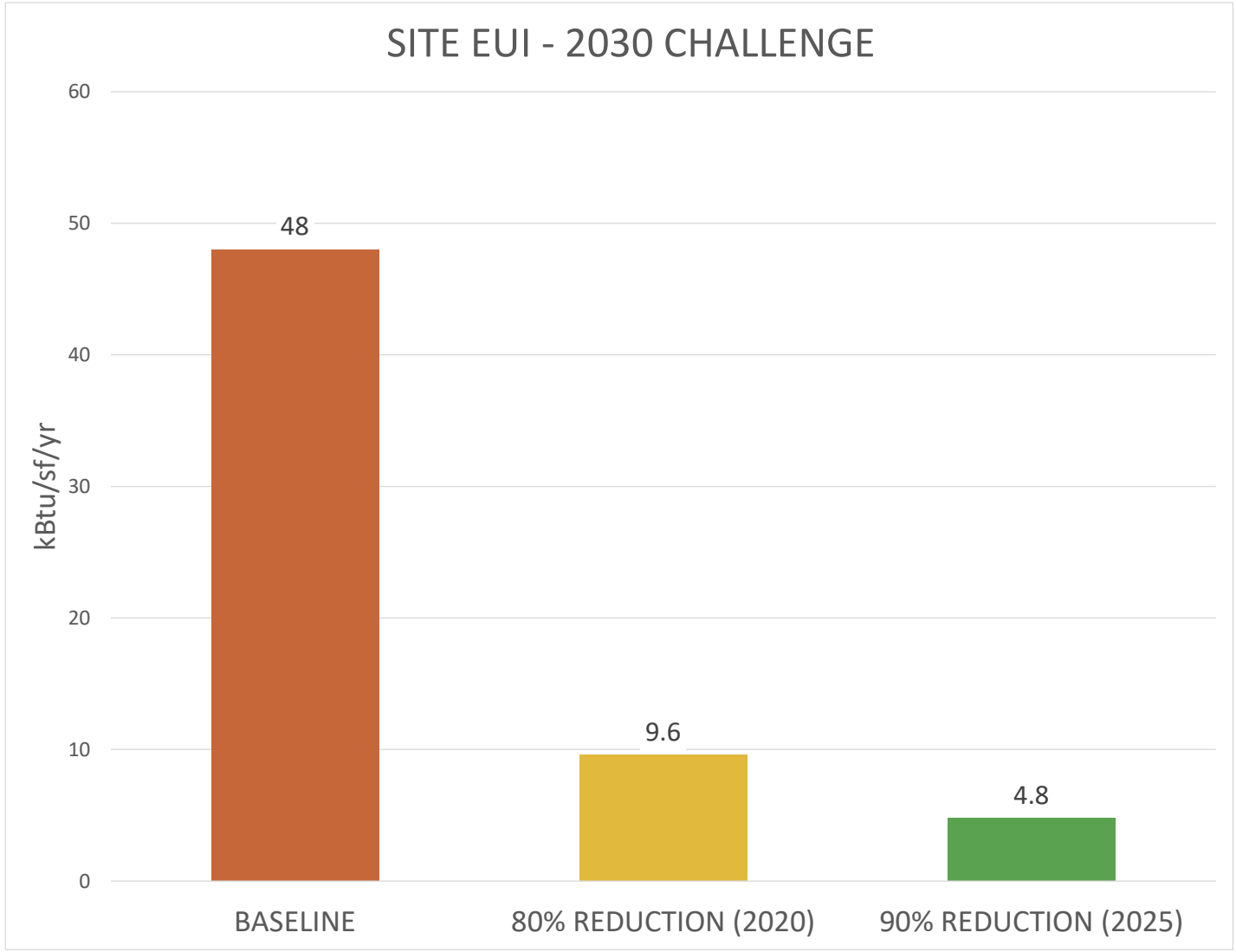
- Baseline calculated using Architecture 2030 Zero Tool
- EUI Actual = based on 2022 utility bill data, takes into account reductions from solar power
- Energy Model = based on Revit Insight energy model or third party energy model

Conversion Factors

1 kBtu =
0.010002387669961 therms (natural gas)
0.293014534 kWh (electricity)

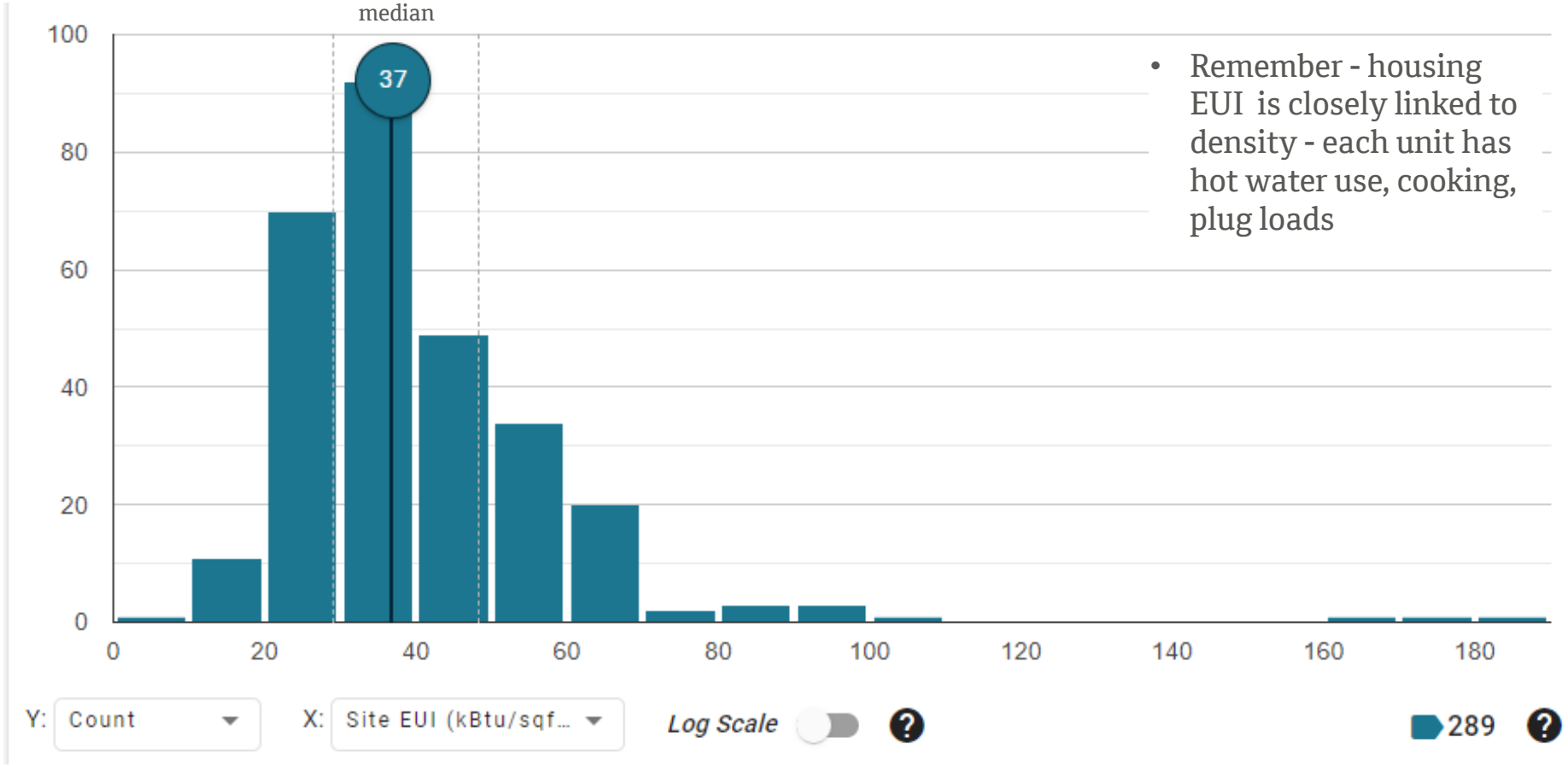


OPERATIONAL CARBON: 2030 EUI TARGET EXAMPLE



OPERATIONAL CARBON: EUI COMPARISON

SITE EUI: MULTIFAMILY + MIXED USE, BUILT 2015-2022, CLIMATE ZONES 4C + 5B



- Remember - housing EUI is closely linked to density - each unit has hot water use, cooking, plug loads

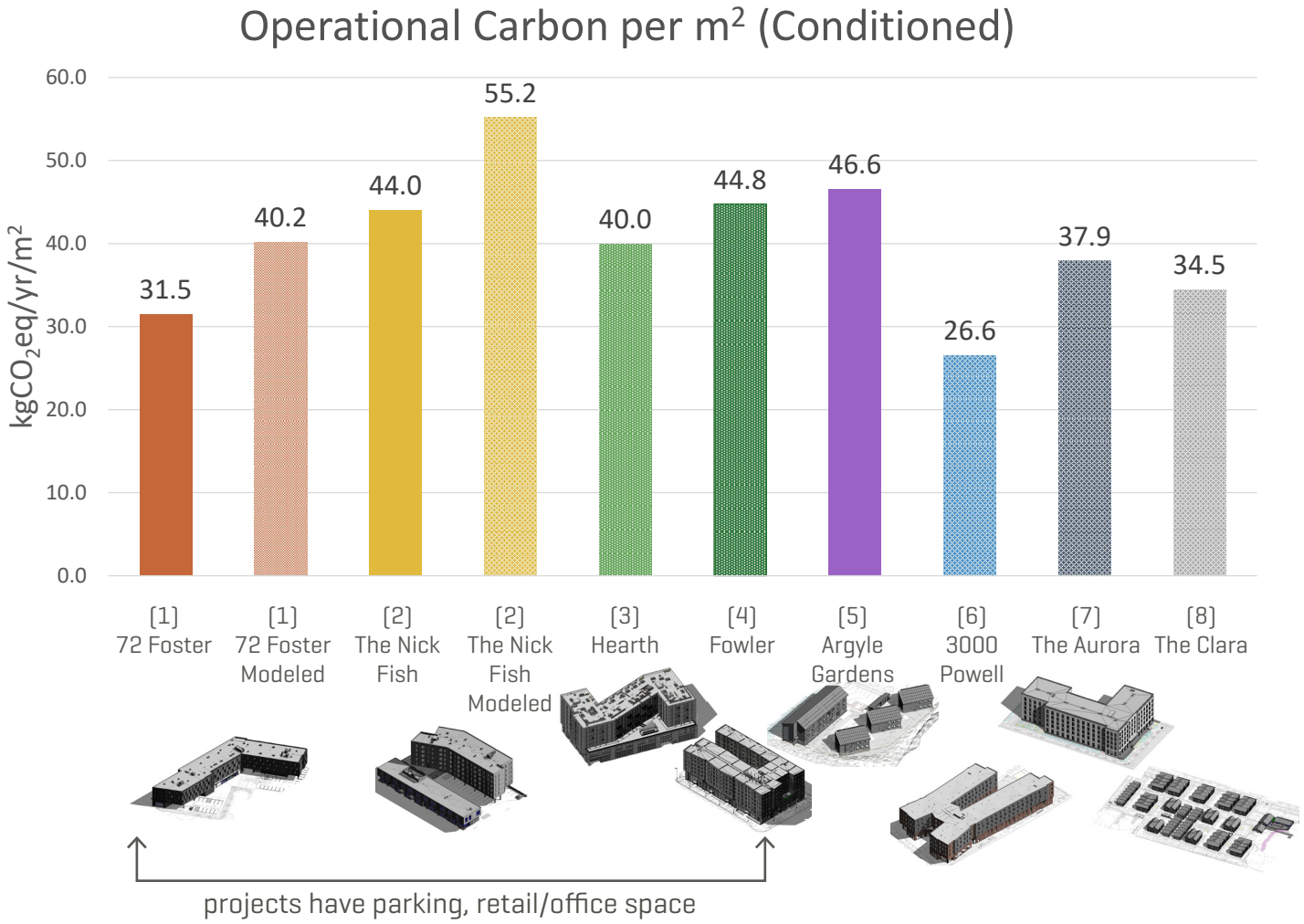
Source: https://bpd.lbl.gov/explore

OPERATIONAL CARBON OPERATIONAL COMPARISONS PER SQUARE METER

- measured (actual) range
  31.5 to 46.6 kg CO_2eq/yr/m²
- range (includes energy models)
  26.6 to 55.2 kg CO_2eq/yr/m²
- Median: 40.1 kg CO_2eq/yr/m²

40.1 kg CO_2 = 103 miles driven*

*Converted using EPA's Greenhouse Gas Equivalencies Calculator
https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator



OPERATIONAL CARBON OPERATIONAL COMPARISONS OF HOUSING EFFICIENCY

- Shows operational carbon in terms of per unit, per bedroom, and per occupant
- This chart does not reflect the additional advantages of the mixed uses in 72 Foster, the Nick Fish, Hearth, and the Fowler.

<u>Per unit*</u>

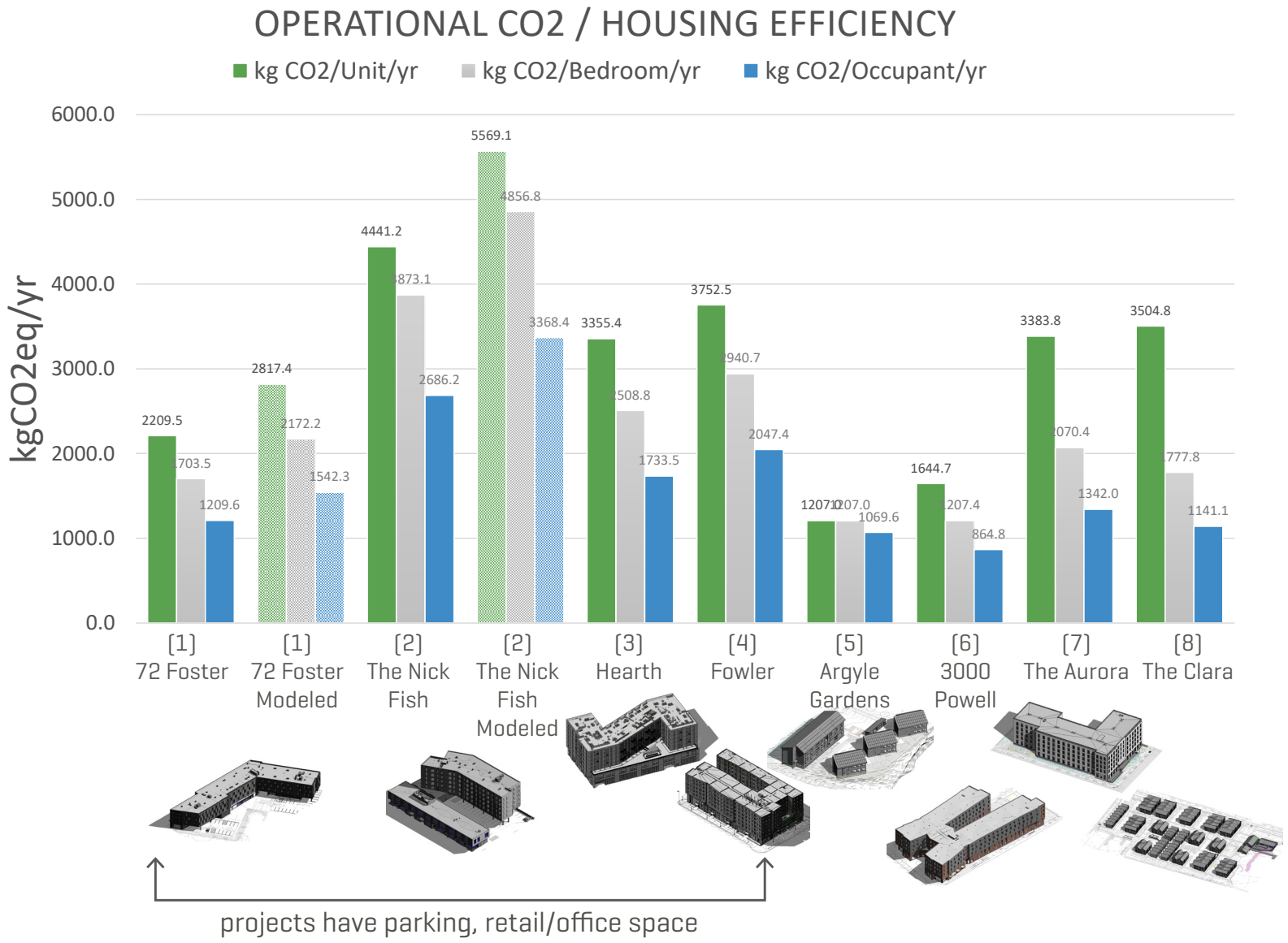
- Low: 1207 kg CO_2eq/unit/yr
- Average**: 2937 kg CO_2eq/unit/yr
- High: 4441 kg CO_2eq/unit/yr

<u>Per occupant*</u>

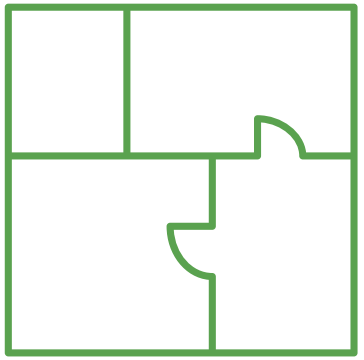
- Low: 865 kg CO_2eq/occ/yr
- Average**: 1512 kg CO_2eq/occ/yr
- High: 2686 kg CO_2eq/occ/yr

*excludes The Nick Fish - Modeled and 72Foster - Modeled

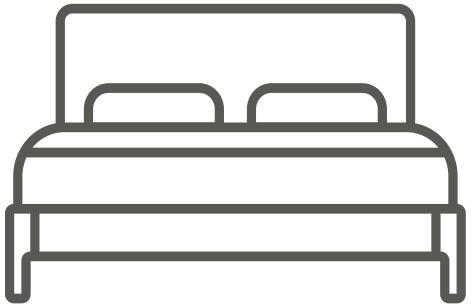
**20% trimmed mean



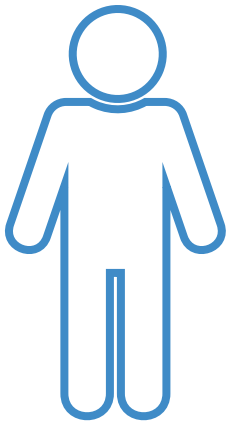
OPERATIONAL CARBON OPERATIONAL COMPARISONS OF HOUSING EFFICIENCY*



Mean:
2937 kg CO_2eq/unit/yr

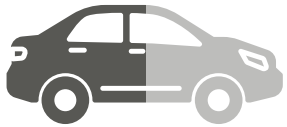


Mean:
2161 kg CO_2eq/bedroom/yr

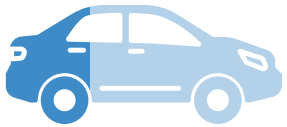


Mean:
1512 kg CO_2eq/occ/yr

= .65 gasoline-powered car driven for one year (7,529 miles driven)



= .48 gasoline-powered car driven for one year (5,540 miles driven)



= .34 gasoline-powered car driven for one year (3,876 miles driven)

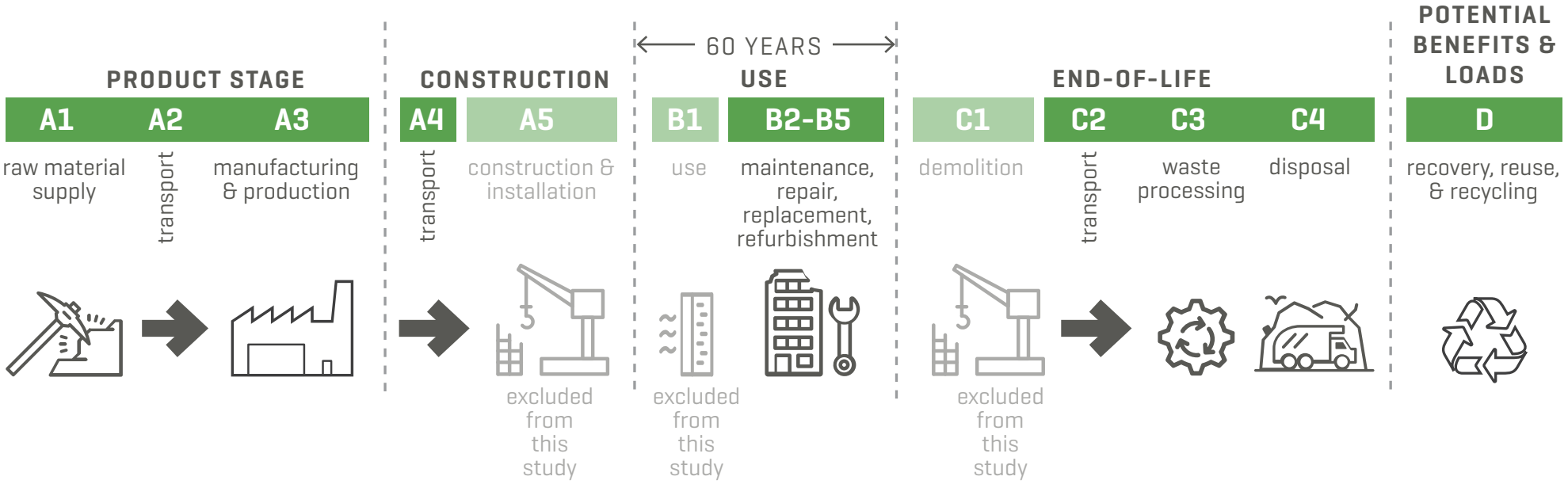
*Converted using EPA's Greenhouse Gas Equivalencies Calculator https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

**Mean values are 20% trimmed means

EMBODIED CARBON

EMBODIED CARBON METHODOLOGY: BACKGROUND

LIFE CYCLE STAGES & MODULES

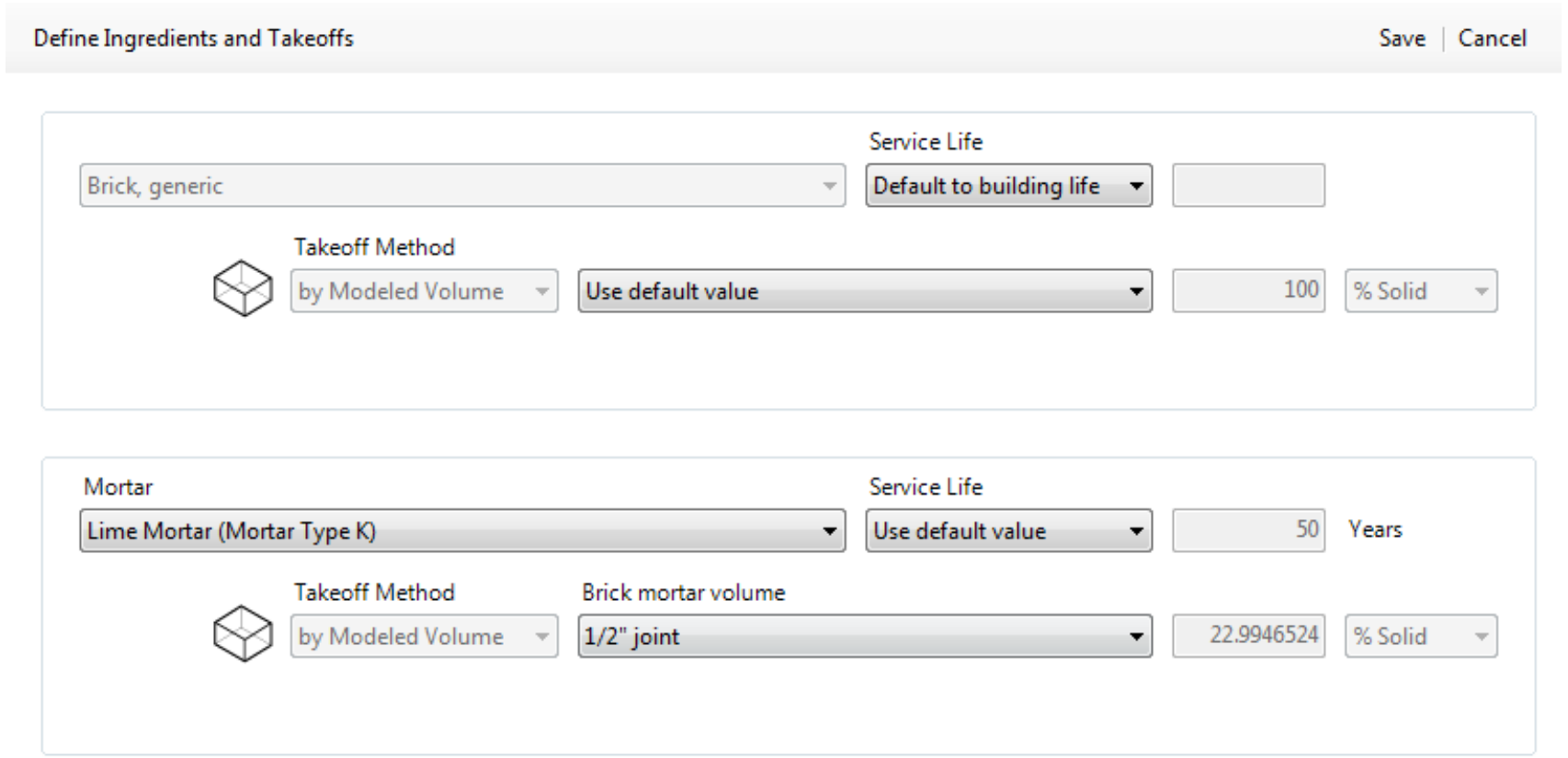


31.75%

biogenic carbon storage at end of life

EMBODIED CARBON METHODOLOGY: BACKGROUND - TALLY

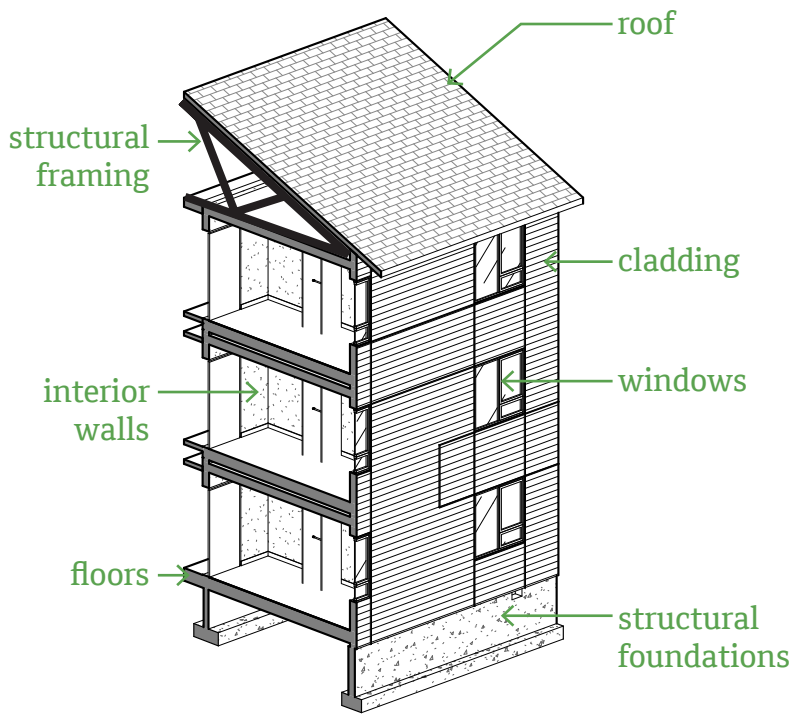
REVIT



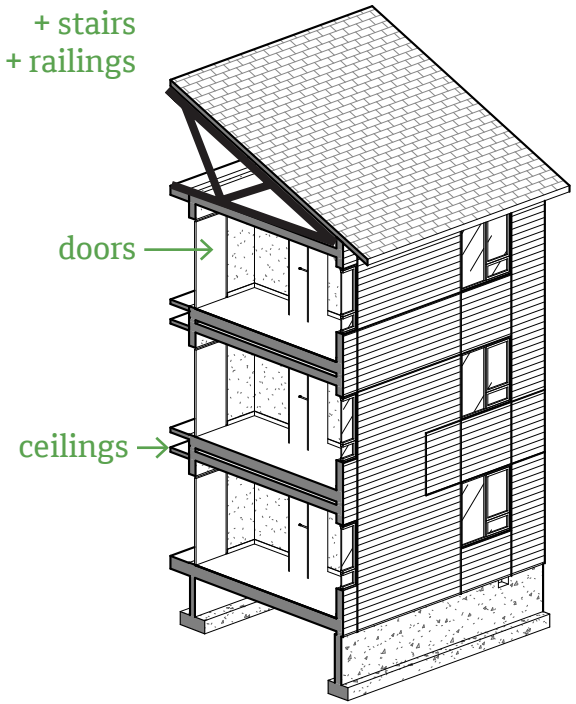
Material Quantity x Material Carbon Intensity = Embodied Carbon

EMBODIED CARBON METHODOLOGY: SCOPE

BASE SCOPE INCLUDES



FULL SCOPE INCLUDES BASE SCOPE + ADDITIONAL CATEGORIES



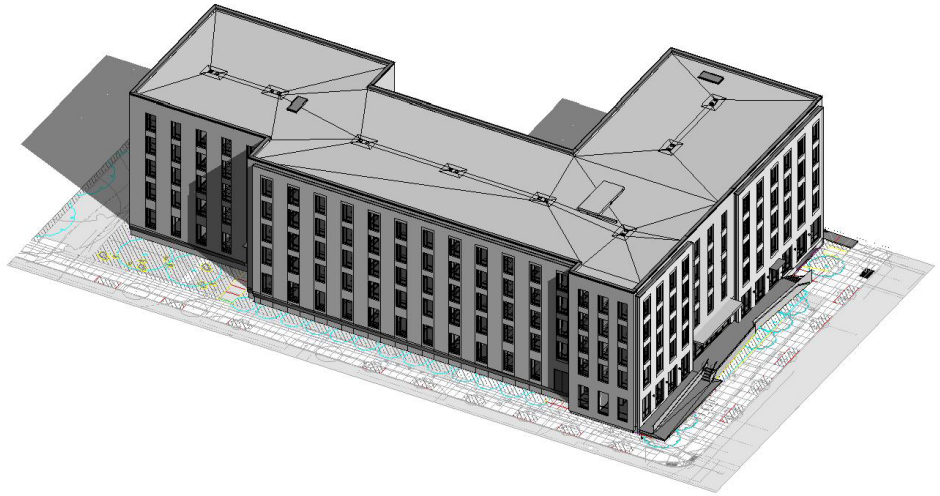
EXCLUDED SCOPE

- MEP
- fire sprinklers and alarms
- casework
- sitework
- elevators
- furnishings
- fixtures/ accessories

LIMITATIONS

- Embodied carbon data for building systems is almost non-existant
- Lack of data from specific material manufacturers
- Embodied carbon does not take into account other environmental impacts, such as habitat impacts
- Quality of output related to quality of digital building modeling
- Results are an estimate, and can be greatly impacted by end-of-life assumptions

%?



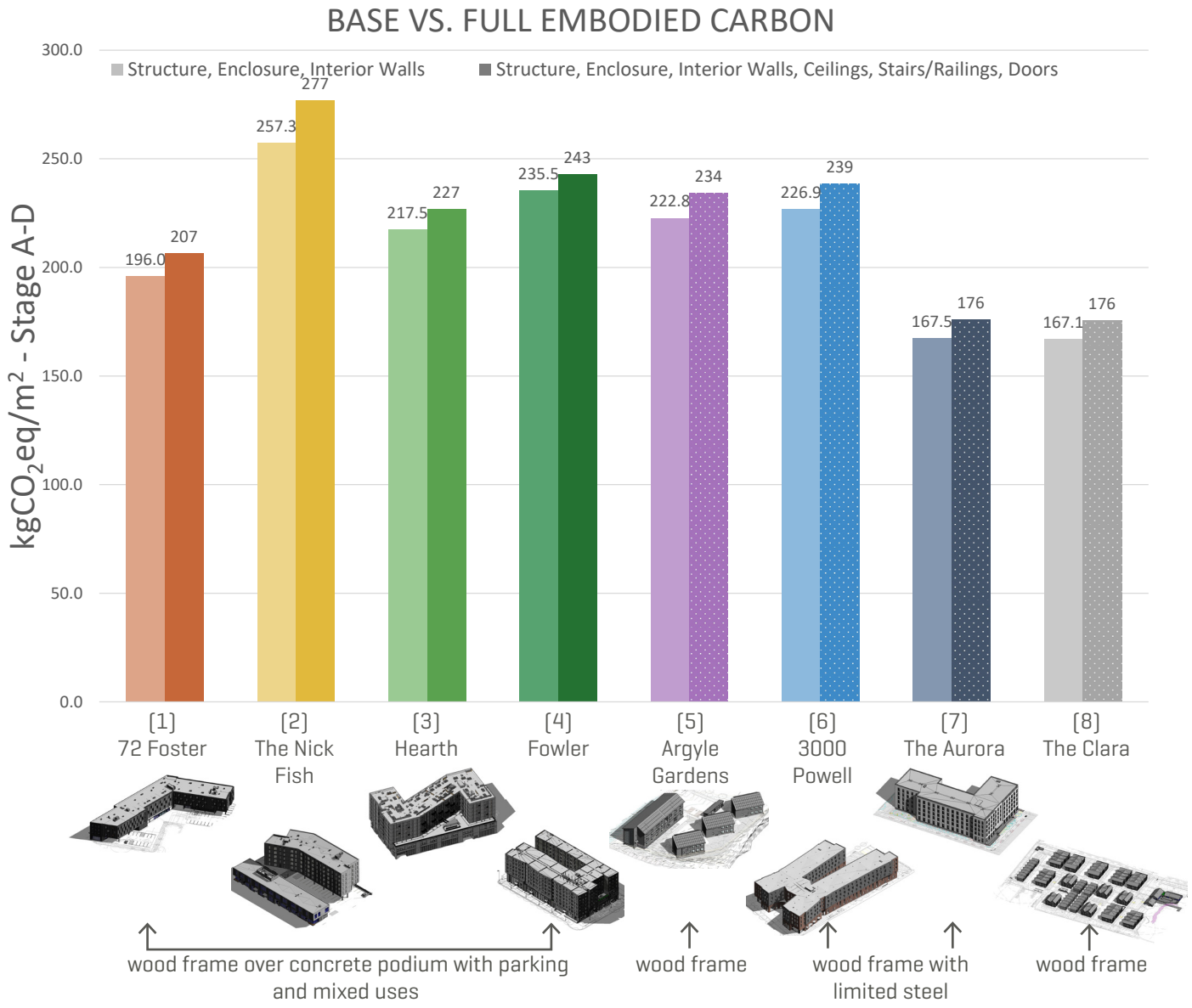
EMBODIED CARBON: BASE VS. FULL

- Including biogenic carbon, normalized by kg CO_2eq per square meter of the building area.
- Base Embodied Carbon:

  Low: 167 kg CO_2eq/m^2

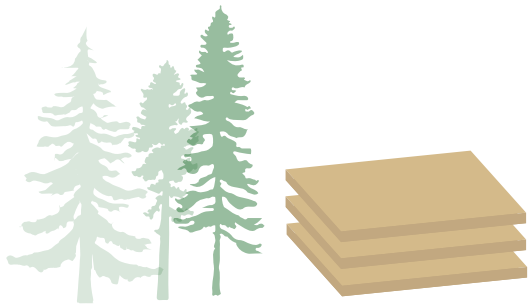
  Average: 219 kg CO_2eq/m^2

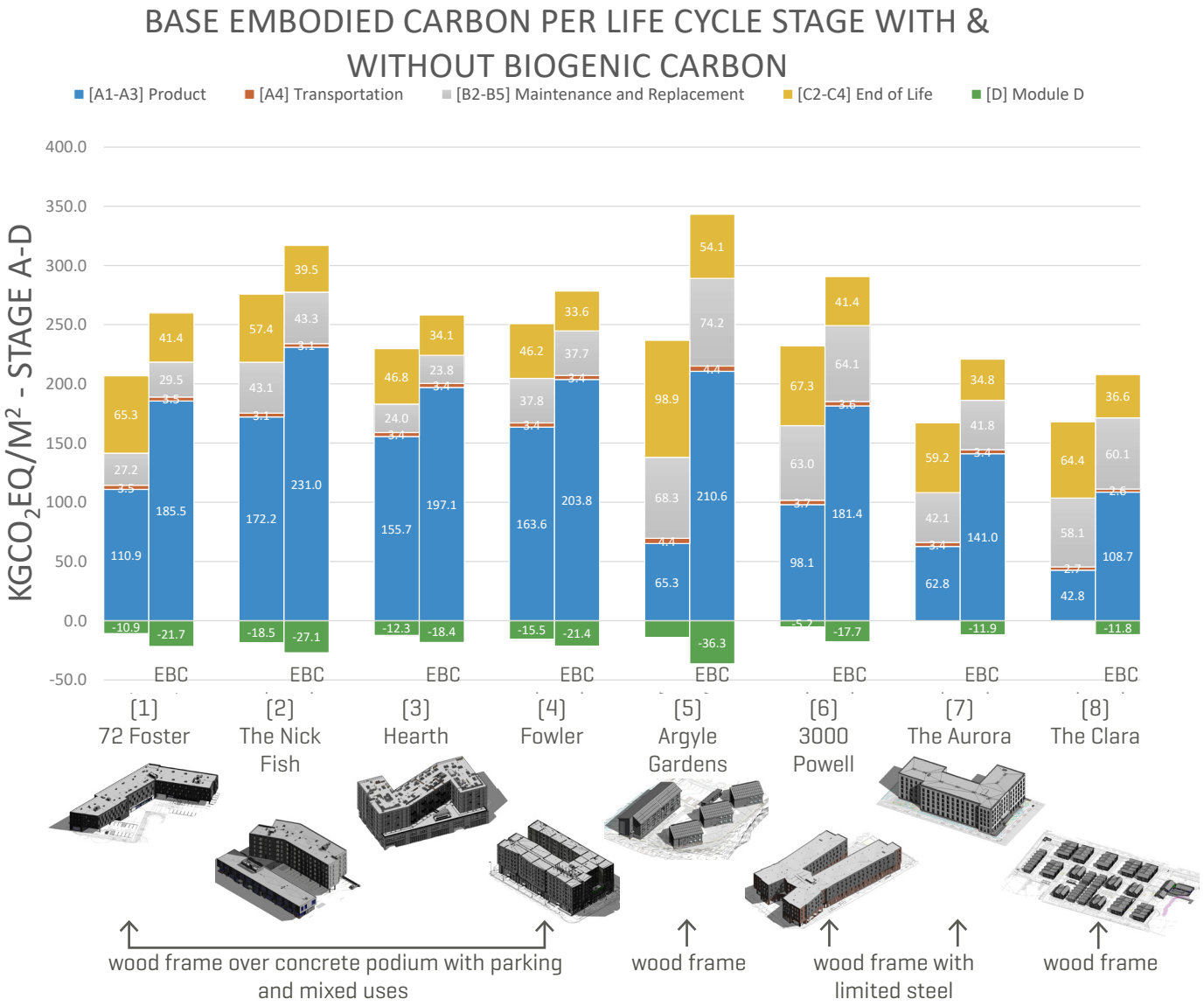
  High: 257 kg CO_2eq/m^2
- 35% difference between the low and high values.
- Stairs, railings, doors, and ceilings contributed an average 5% to the embodied carbon of a project.



EMBODIED CARBON: PER LIFE CYCLE STAGE - INCLUDING AND EXCLUDING BIOGENIC CARBON

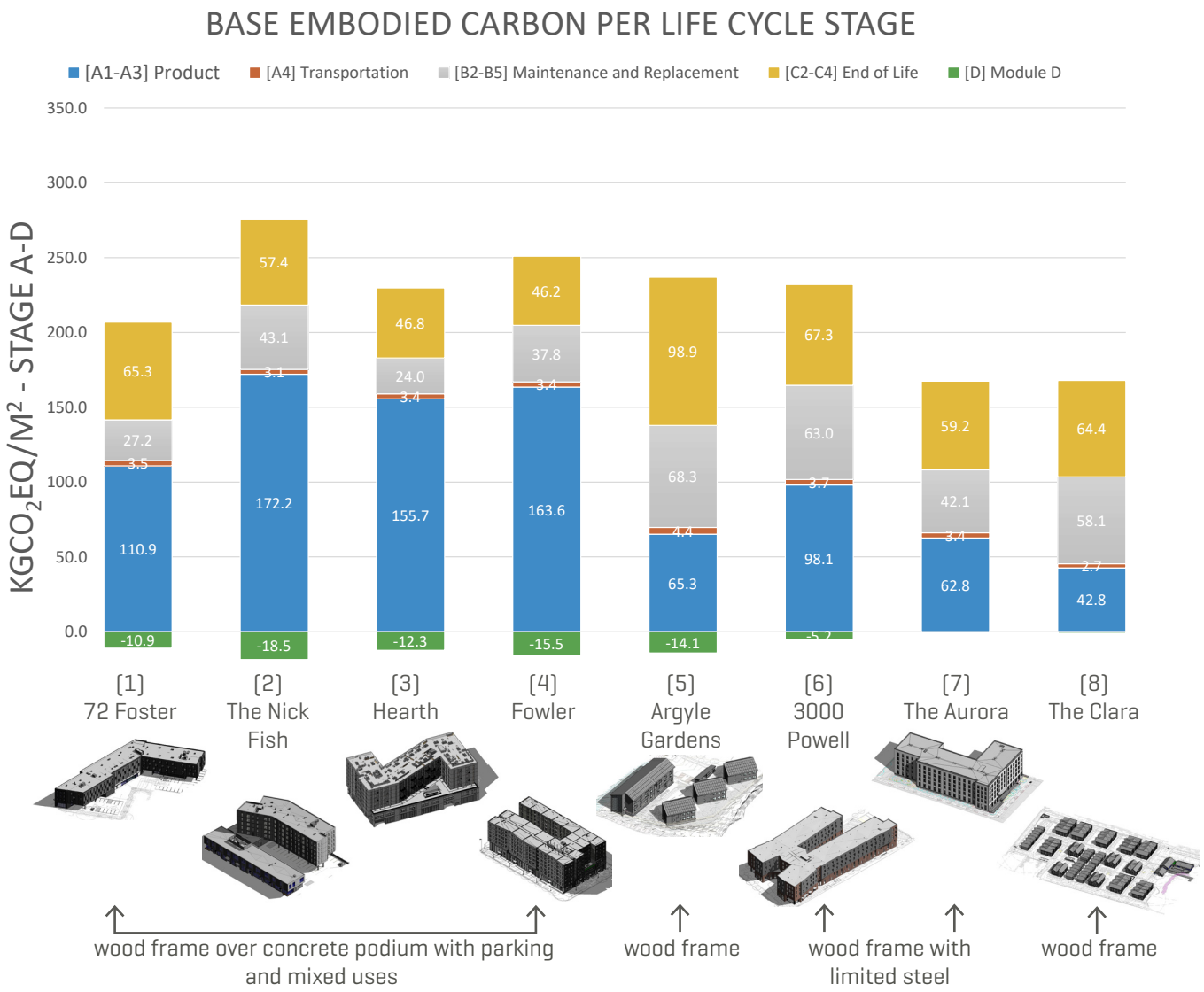
- Comparison of the base embodied carbon per life cycle stage, including and excluding biogenic carbon (EBC).
- **There is a higher total embodied carbon when biogenic carbon is excluded.**
- This variation is most apparent in the Argyle Gardens project, which is a Type V wood construction with small units (primarily single room occupancy) with two and three story buildings.



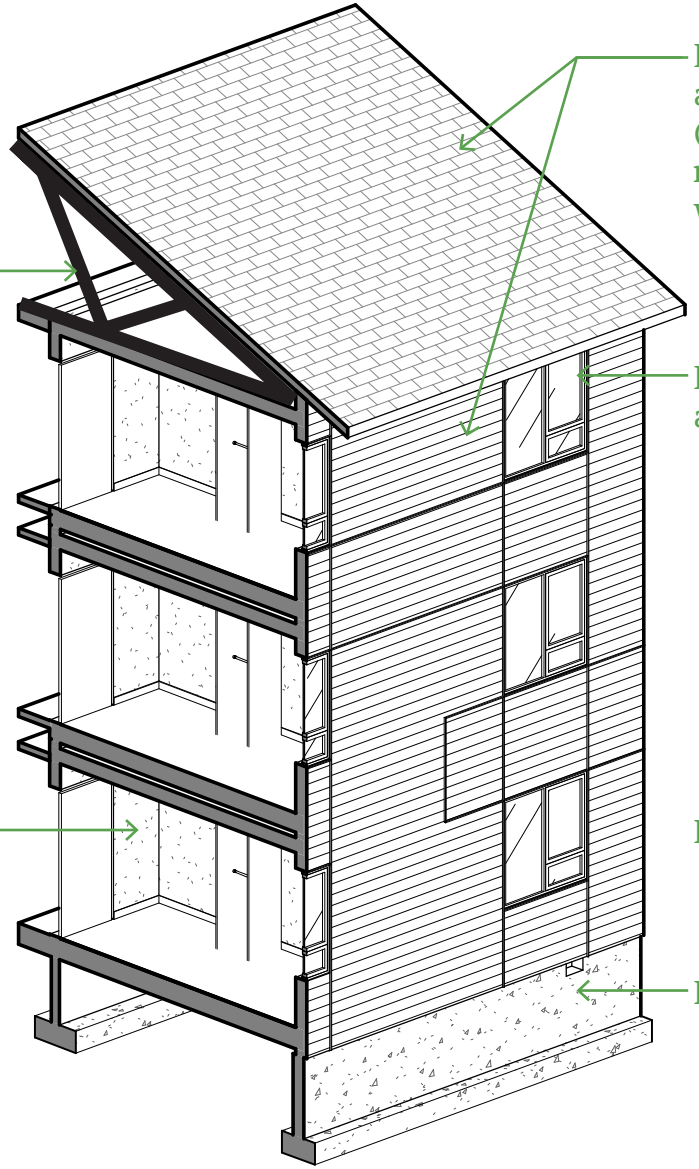


EMBODIED CARBON: PER LIFE CYCLE STAGE

- This chart compares the base embodied carbon per life cycle stage (includes biogenic carbon).
- Concrete podium buildings: **Stage A (product) is greatest contributor**
- Wood frame buildings: **Stage B & C (use and end of life) are greatest contributor**
- Wood frame buildings shift the embodied carbon burden towards the use and end-of-life stage to optimize savings today.



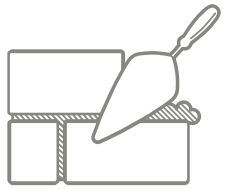
EMBODIED CARBON: PER DIVISION



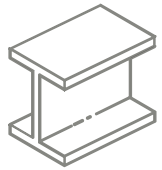
Division 07: Thermal and Moisture Protection (includes insulation, roofing, siding, waterproofing)

Division 06: Wood, Plastics, & Composites

Division 08: Openings and Glazing



Division 04: Masonry (includes brick and cmu)



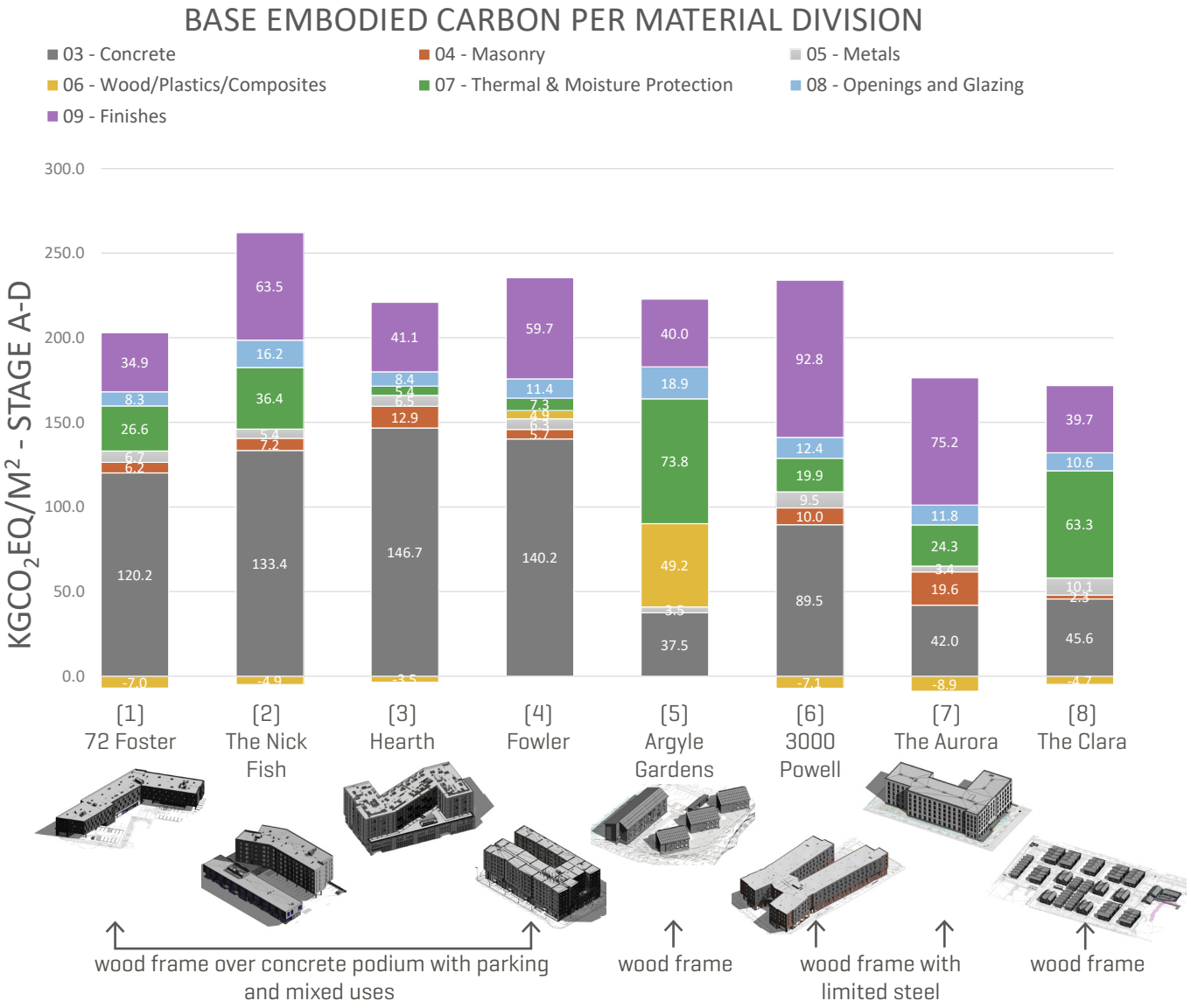
Division 05: Metals

Division 09: Finishes (includes drywall, paint, ceilings, etc.)

Division 03: Concrete

EMBODIED CARBON: PER DIVISION

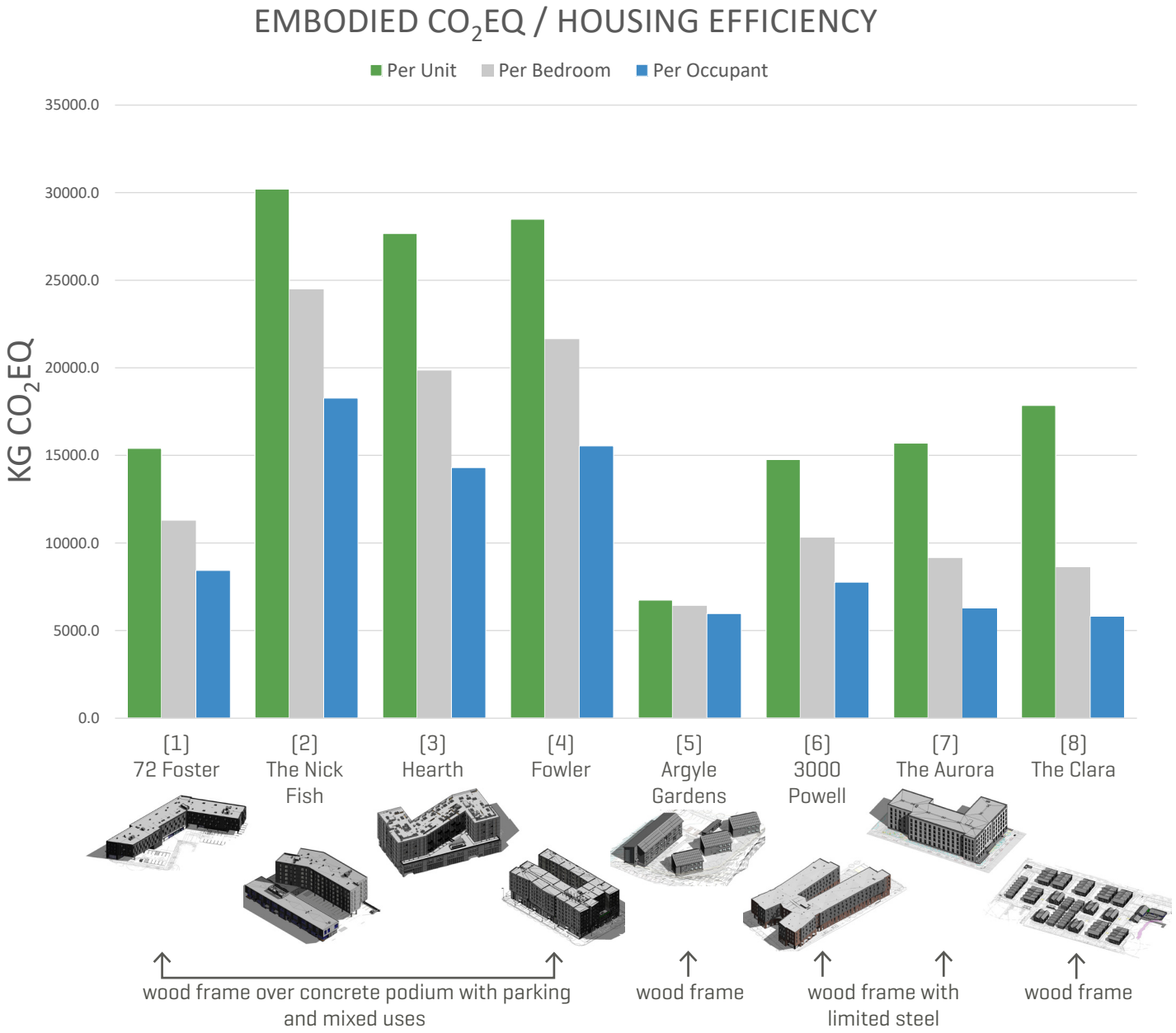
- **Concrete makes up over half of the base embodied carbon for the concrete podium buildings.**
- For the non-concrete podium buildings, the smaller concrete foundations contribute a lower percentage to the embodied carbon.
- The two and three story projects have a greater surface area ratio, which is likely reflected in the higher embodied carbon of the thermal and moisture protection.
- There is a large variation in finishes, which could relate to the amount of gypsum wallboard needed to achieve fire ratings in different construction types.



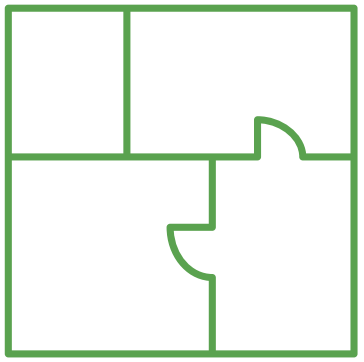
EMBODIED CARBON: HOUSING EFFICIENCY

- Embodied carbon per unit, per bedroom, and per occupant can provide more insight than just looking at the embodied carbon per square meter.
- Four of the projects contain office, retail, or parking uses, which is reflected in the lower housing efficiency for the embodied carbon.
- Mean* (Over 60 years):
  - 19,604 kg CO_2eq/unit
  - 13,965 kg CO_2eq/bedroom
  - 10,290 kg CO_2eq/occupant
- Mean* (Per year):
  - 326 kg CO_2eq/unit
  - 233 kg CO_2eq/bedroom
  - 172 kg CO_2eq/occupant

*20% trimmed mean

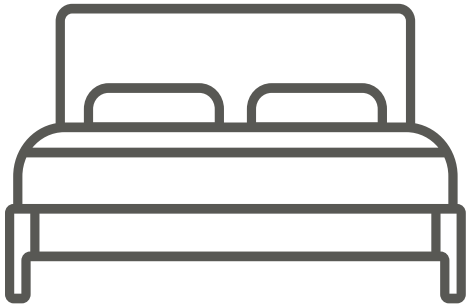


EMBODIED CARBON EMBODIED COMPARISONS OF HOUSING EFFICIENCY



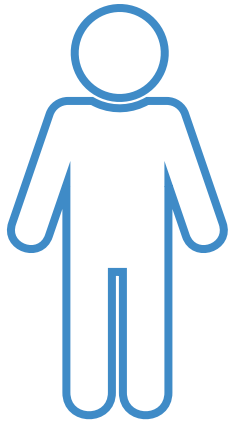
Mean:

326 kg CO_2eq/unit/yr



Mean:

233 kg CO_2eq/bedroom/yr



Mean:

172 kg CO_2eq/occ/yr

= .073 gasoline-powered car driven for one year (836 miles driven)

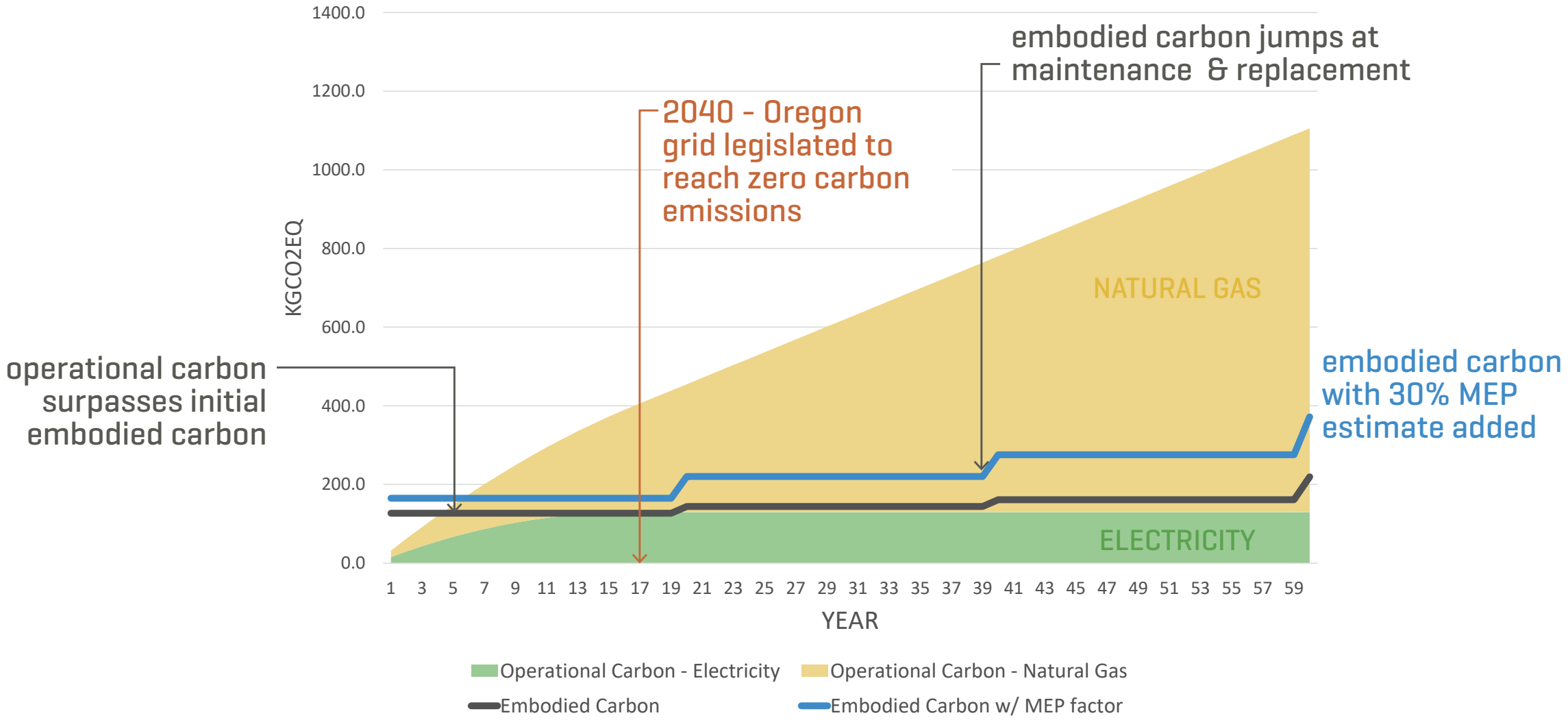
= .052 gasoline-powered car driven for one year (597 miles driven)

= .038 gasoline-powered car driven for one year (441 miles driven)

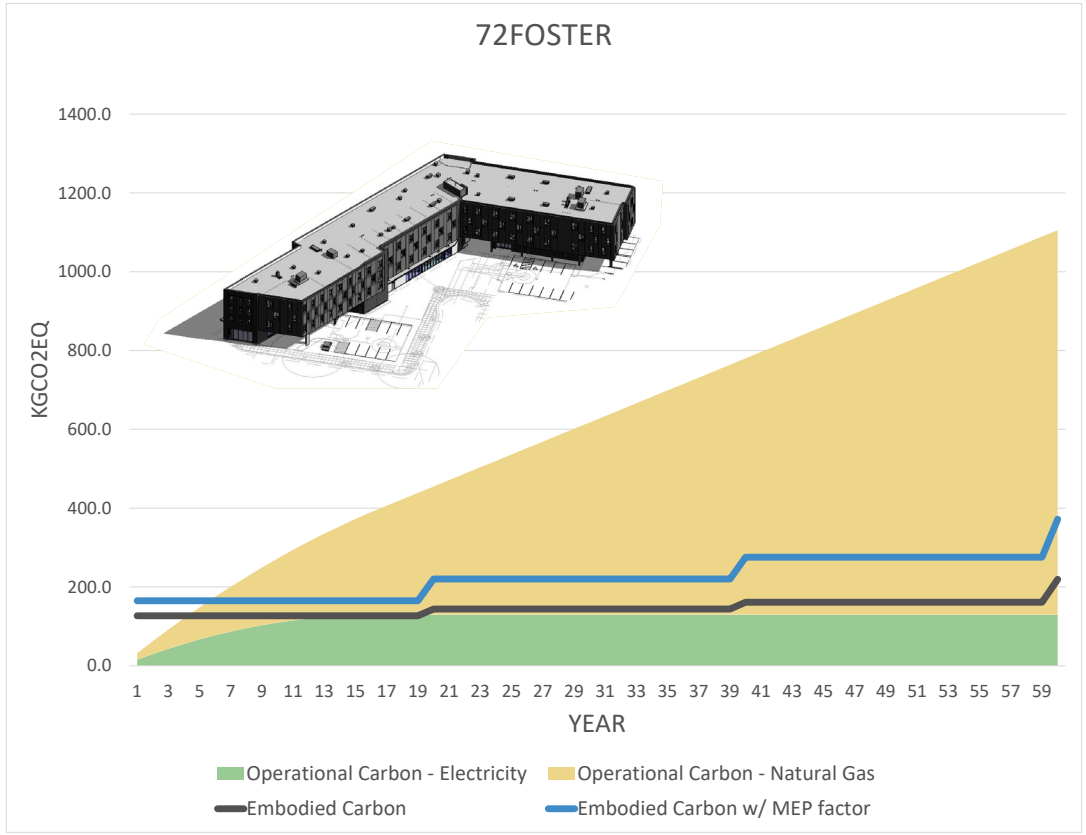
*20% trimmed mean

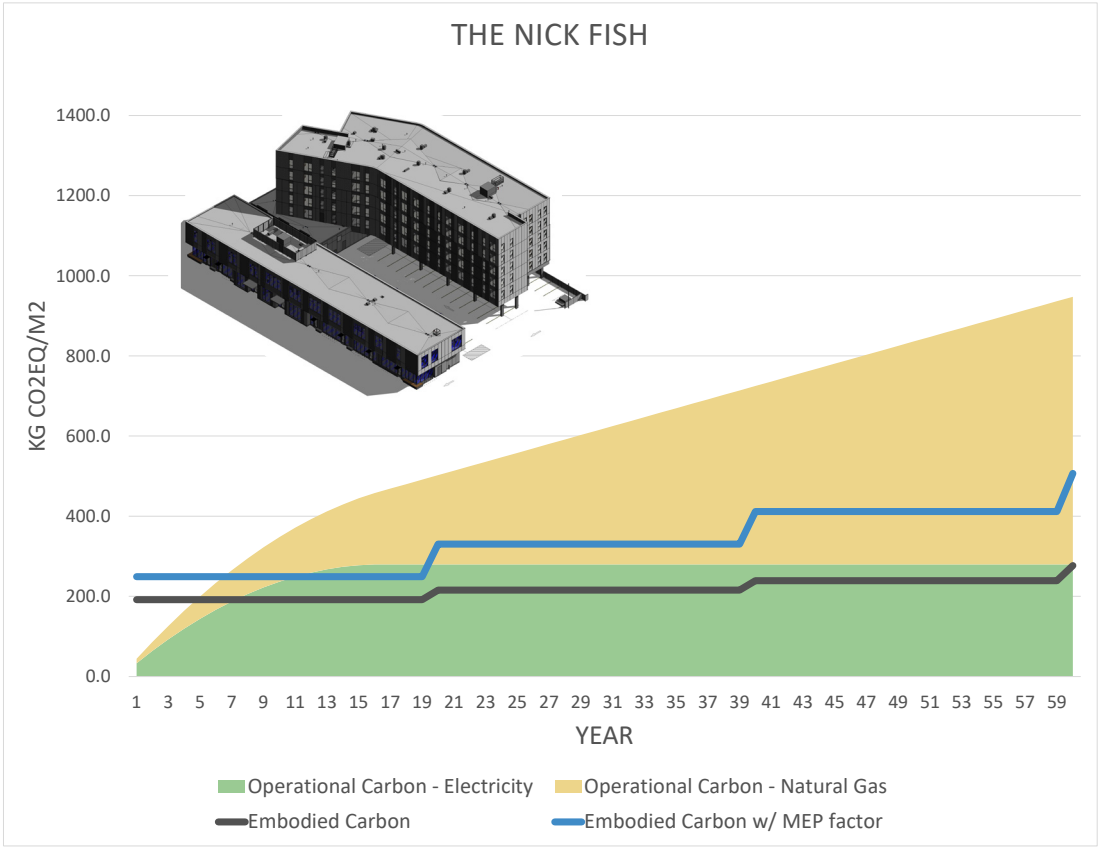
EMBODIED VS. OPERATIONAL

EMBODIED VS. OPERATIONAL - CUMULATIVE EMISSIONS



EMBODIED VS. OPERATIONAL: 72FOSTER & THE NICK FISH | CUMULATIVE EMISSIONS

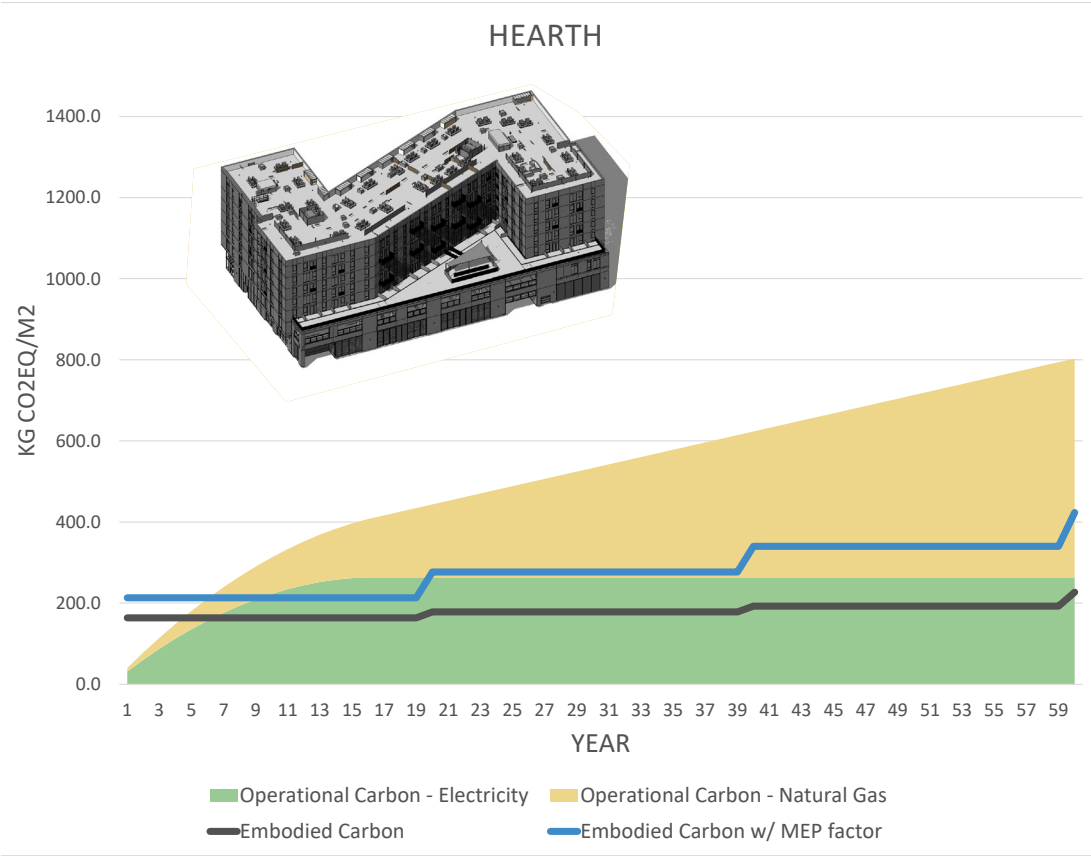


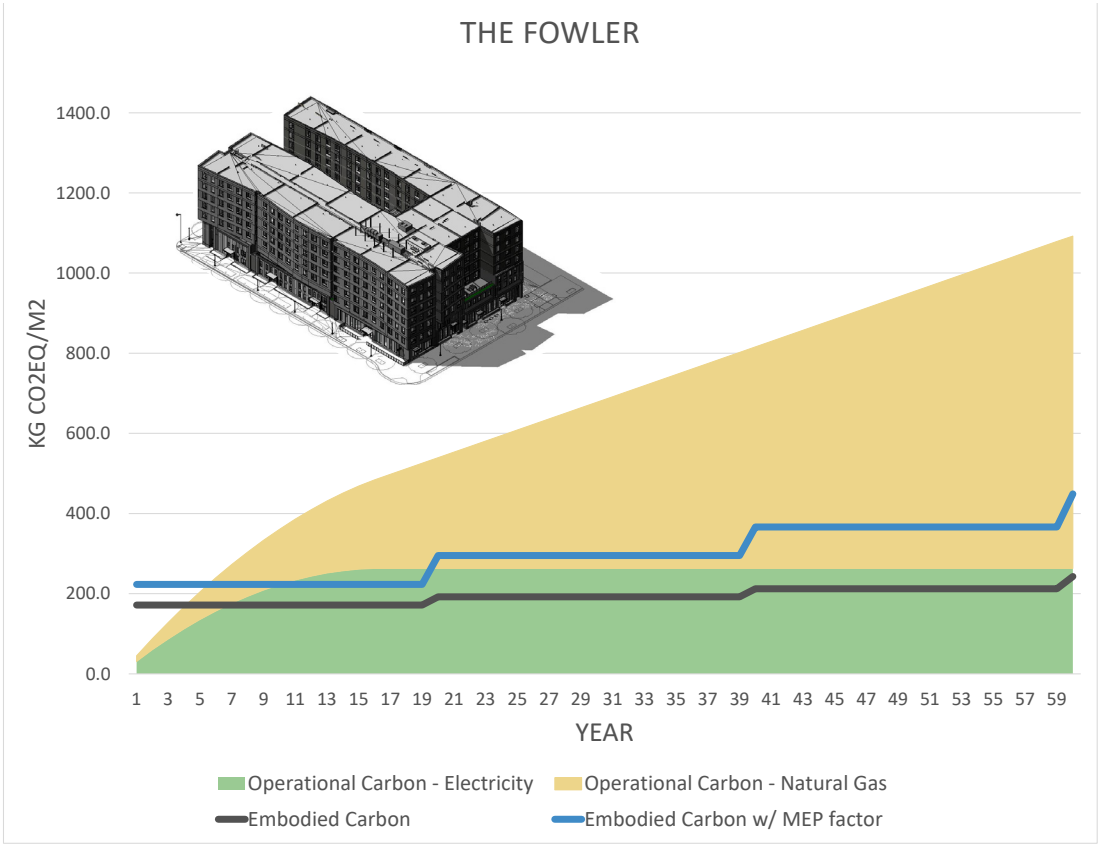


- This project has a large solar panel installation & relatively low portion of operational carbon from electricity.

- At the end-of-life, the embodied carbon makes up 35% of the whole life carbon if the MEP factor is included.

EMBODIED VS. OPERATIONAL: HEARTH & THE FOWLER | CUMULATIVE EMISSIONS

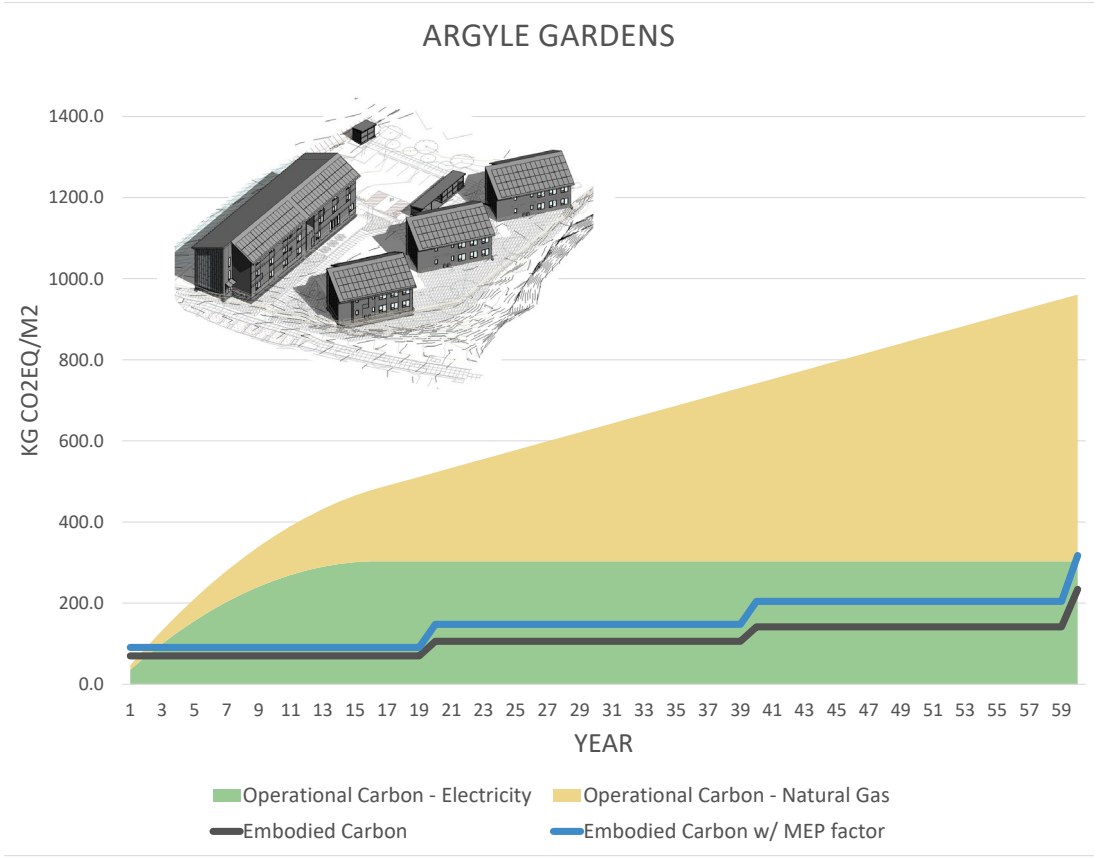




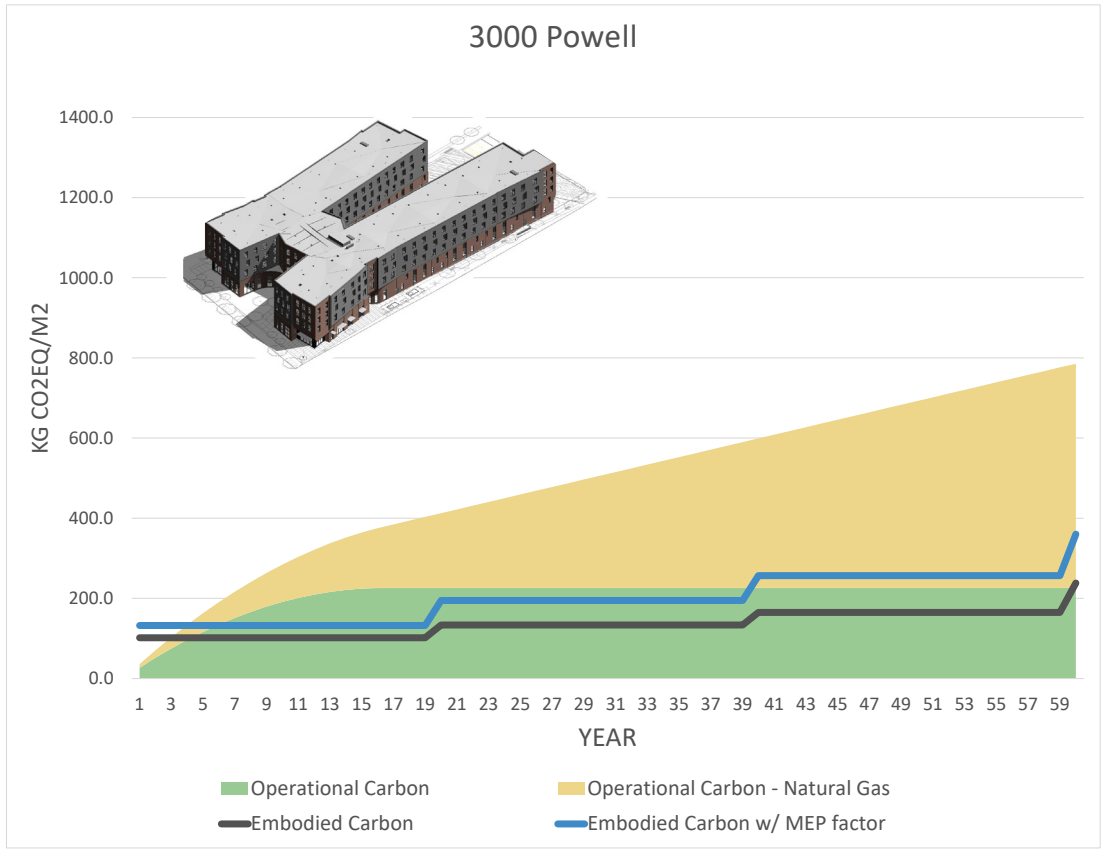
- Lower operational carbon from natural gas than the Fowler.
- Similar embodied carbon to the Fowler

- At the end-of-life, the embodied carbon makes up 30% (the Fowler) and 35% (Hearth) of the whole life carbon if the MEP factor is included.

EMBODIED VS. OPERATIONAL: ARGYLE GARDENS & 3000 POWELL | CUMULATIVE EMISSIONS

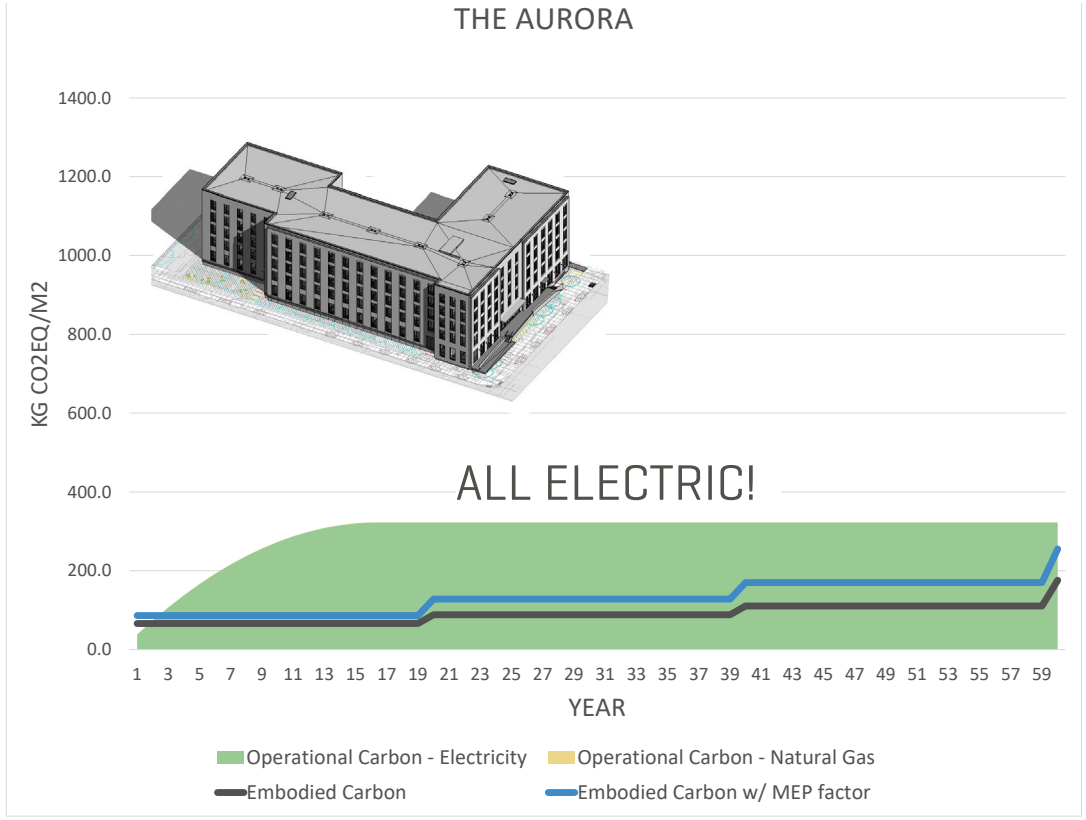


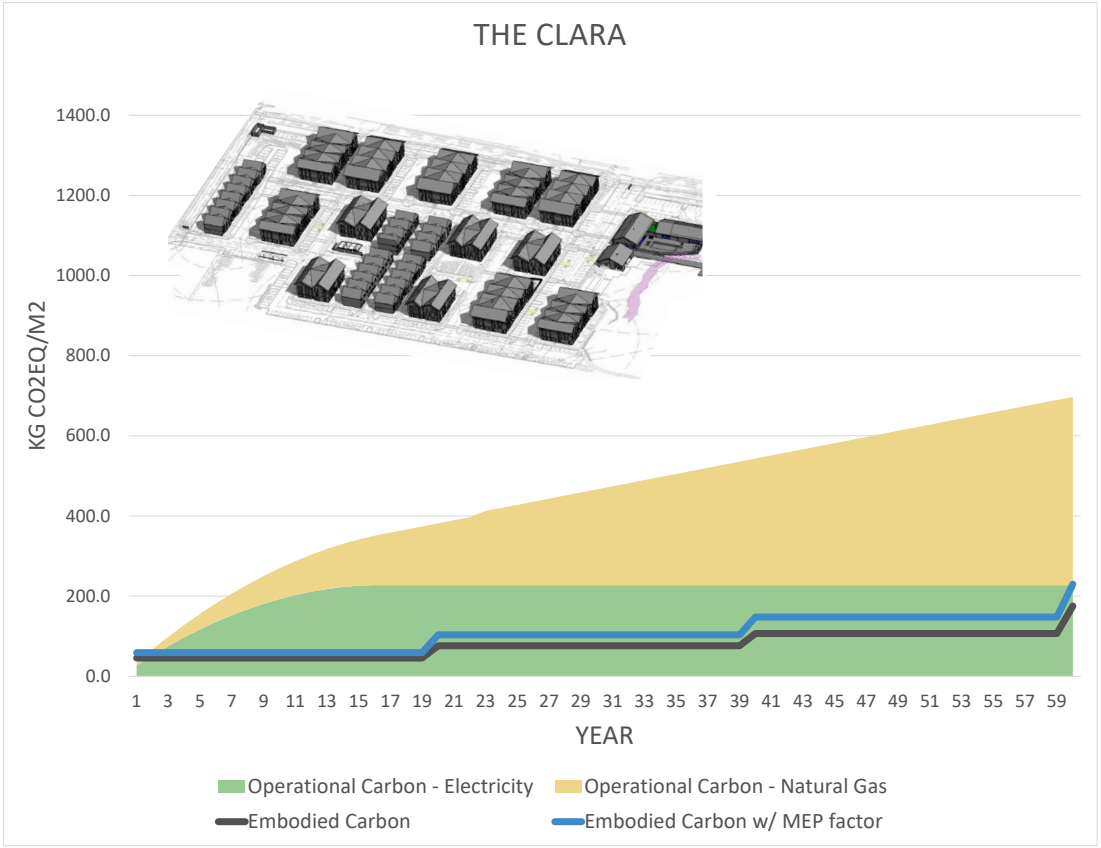
- At the end-of-life, the embodied carbon makes up 25% of the whole life carbon if the MEP factor is included.



- At the end-of-life, the embodied carbon makes up 32% of the whole life carbon if the MEP factor is included.

EMBODIED VS. OPERATIONAL: THE AURORA & THE CLARA | CUMULATIVE EMISSIONS

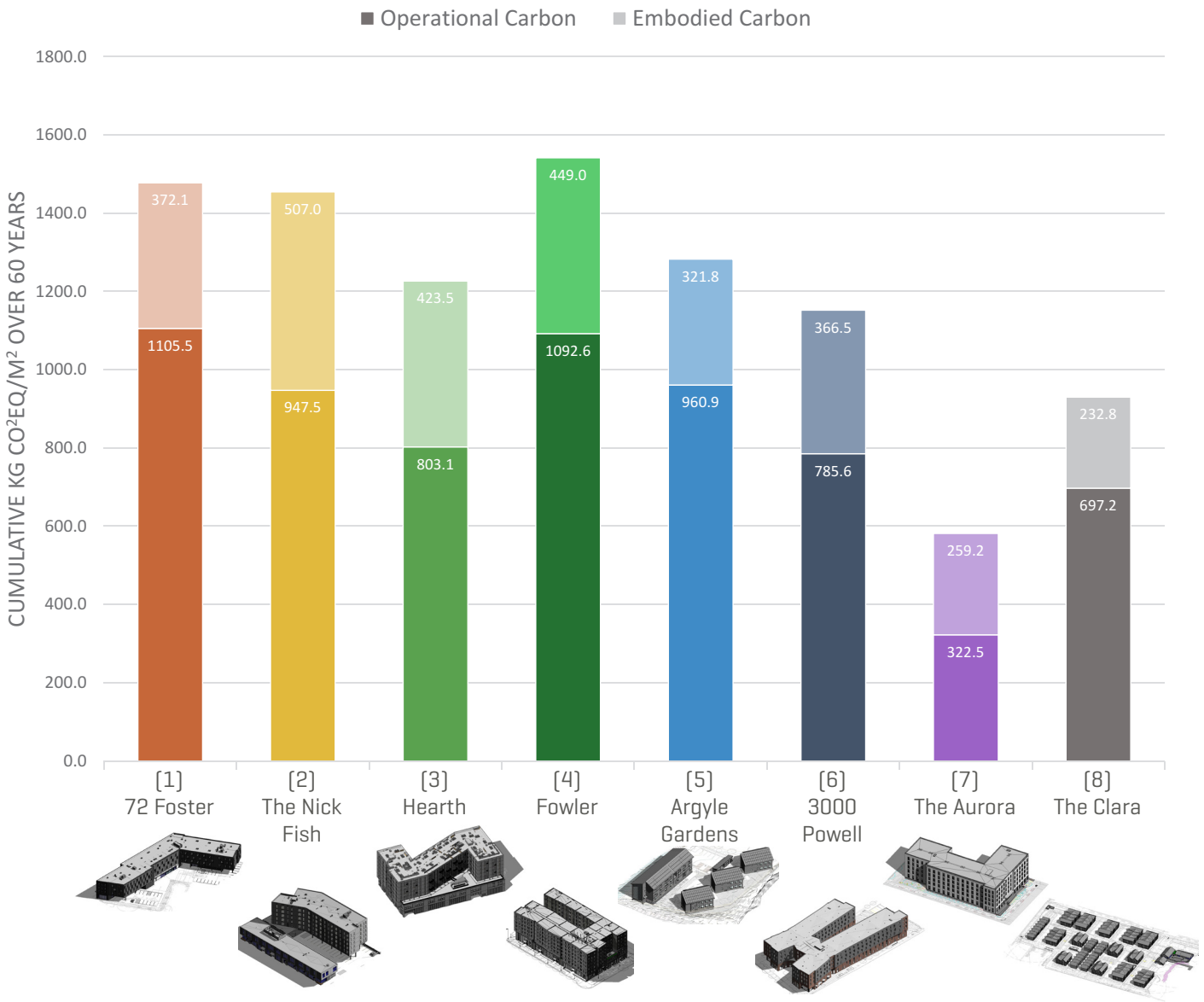




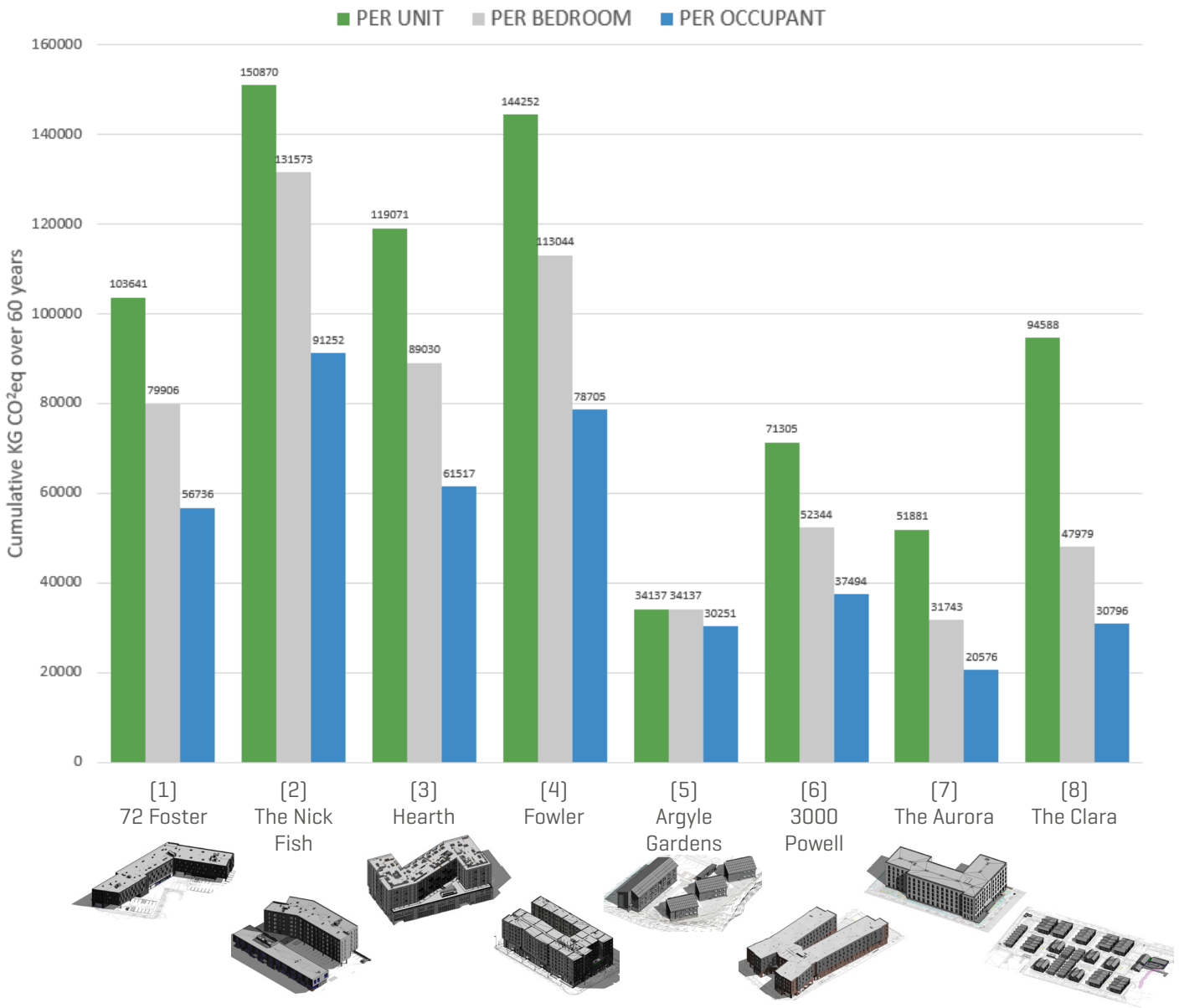
- At the end-of-life, the embodied carbon makes up 45% of the whole life carbon if the MEP factor is included.

- At the end-of-life, the embodied carbon makes up 25% of the whole life carbon if the MEP factor is included.

WHOLE LIFE CARBON: PER SQUARE METER



WHOLE LIFE CARBON: PER UNIT, PER BEDROOM, PER OCCUPANT

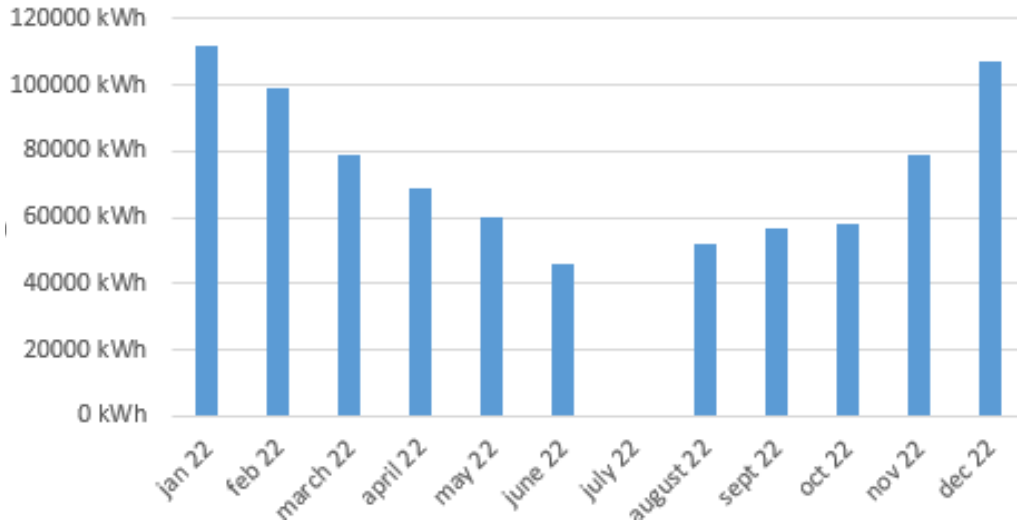


CONCLUSIONS

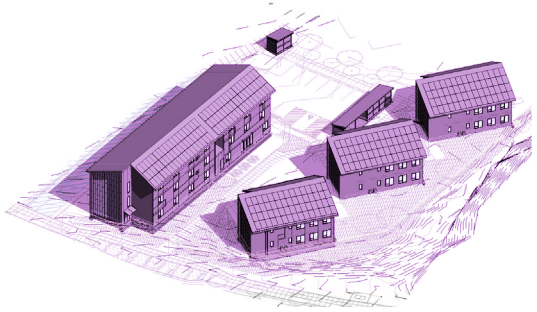
CONCLUSIONS & FINDINGS

1) OPERATIONAL ENERGY USAGE REPORTING SHOULD BE PLANNED FOR BEFORE A PROJECT IS COMPLETE.

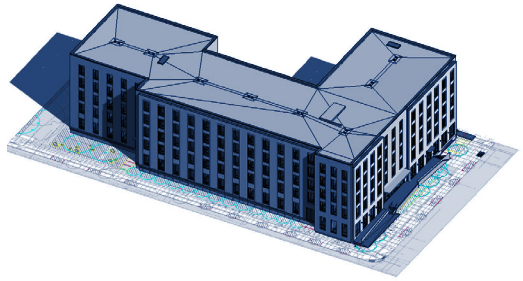
- DATA SHARING WITH ARCHITECTS & ENGINEERS: FEEDBACK LOOP
- WRITTEN INTO LEASES
- YEARLY REVIEWS FOR EFFICIENCY



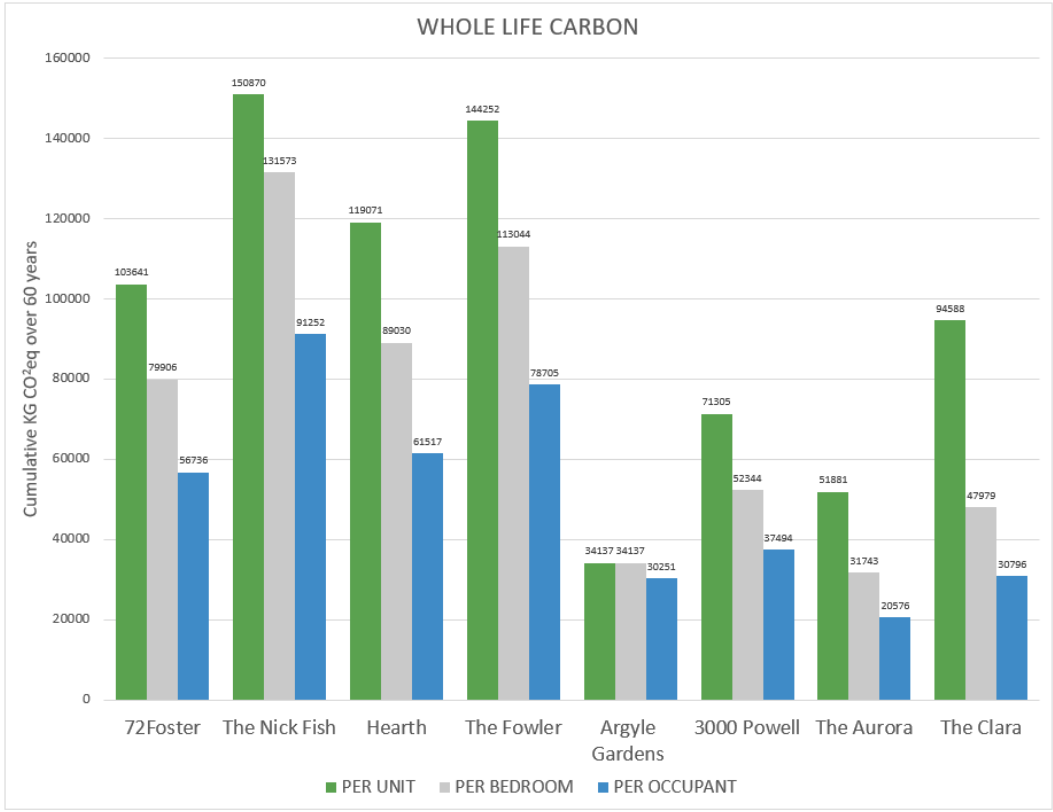
CONCLUSIONS & FINDINGS



ARGYLE GARDENS



THE AURORA

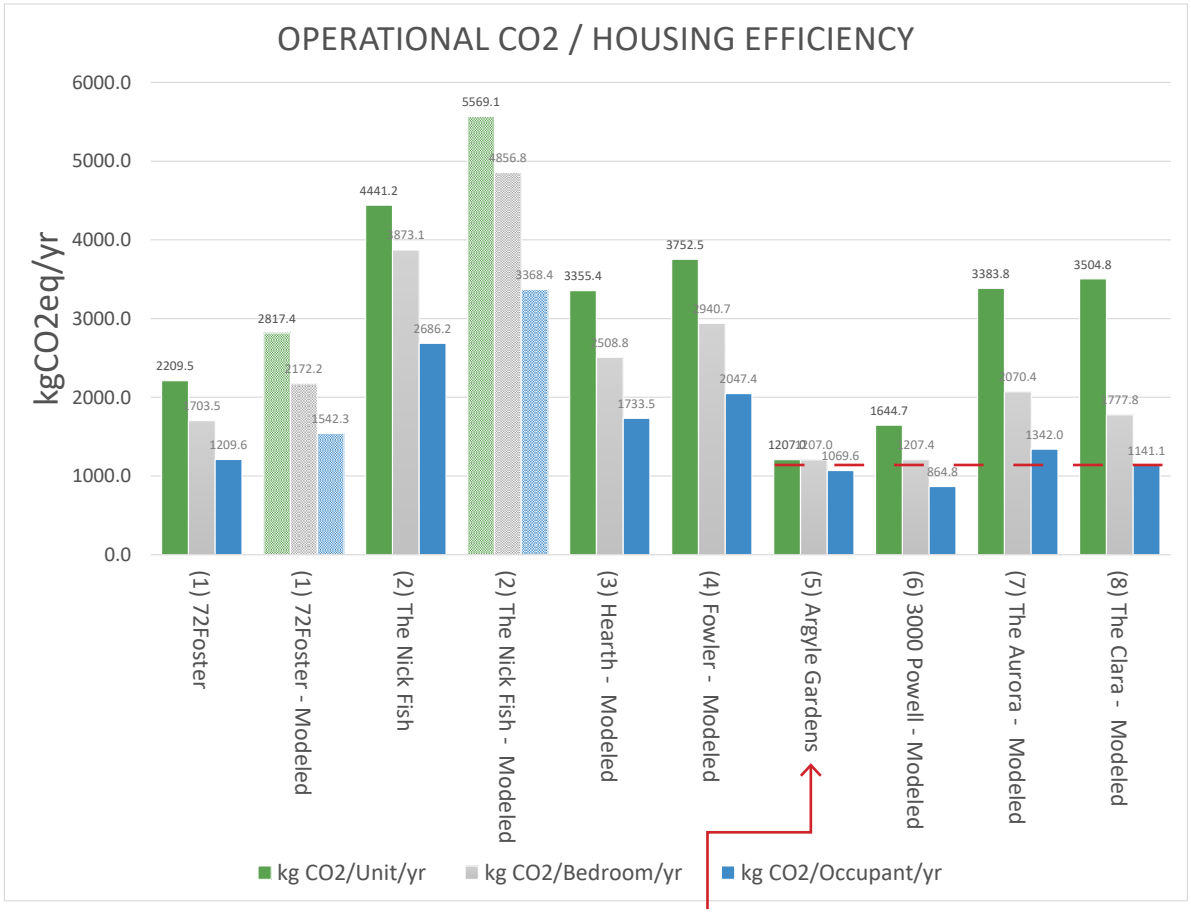


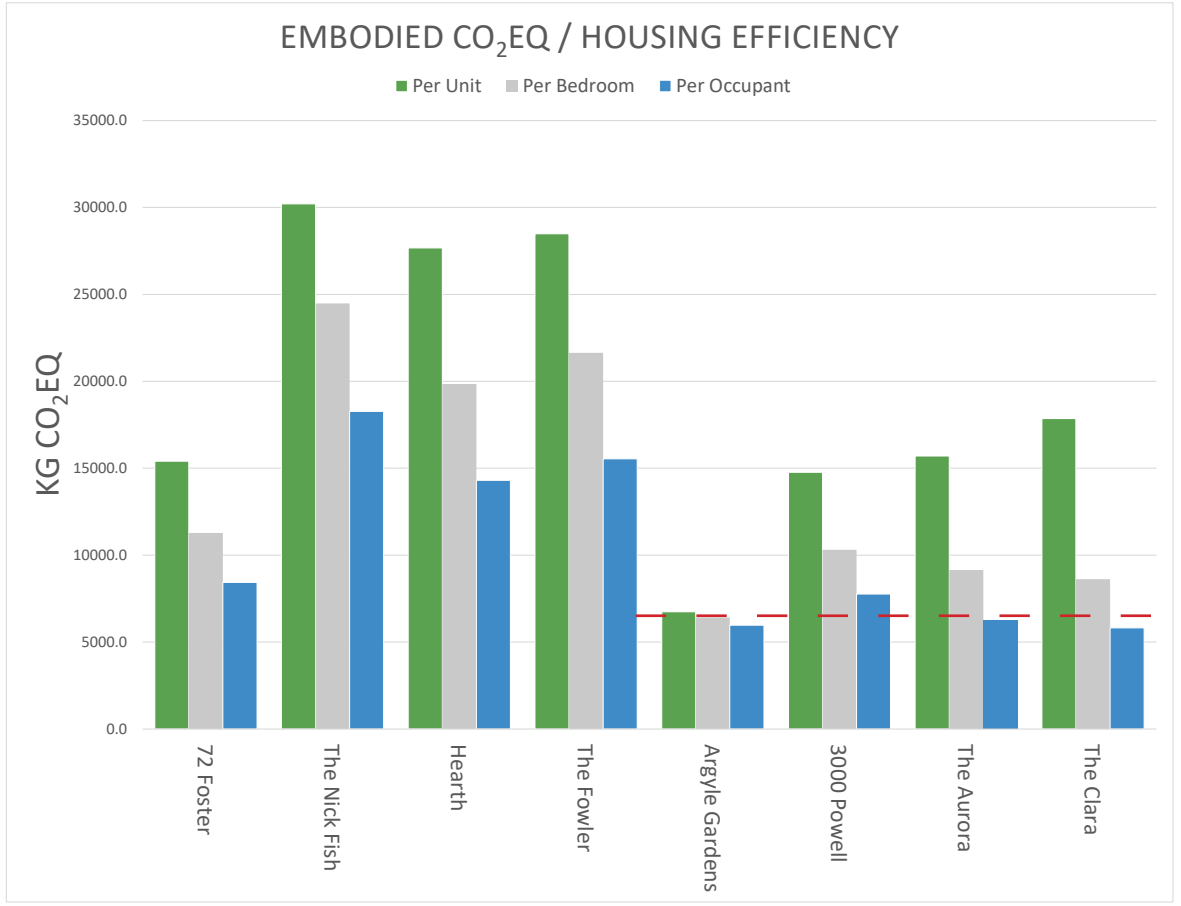
2) ALTHOUGH **ARGYLE GARDENS IS THE MOST EFFICIENT PRESENT-DAY** OPERATIONAL AND EMBODIED CARBON **PER UNIT AND PER BEDROOM, THE AURORA HAS THE LOWEST WHOLE LIFE CARBON** PER BEDROOM/OCCUPANT DUE TO BEING ALL-ELECTRIC.

WHY ARGYLE GARDENS?

- Small unit size
- SRO units share kitchens and bathrooms
- Limited concrete (embodied carbon driver)
- Limited windows (embodied carbon driver)
- Ceiling fans but no air conditioning (operational carbon driver)

CONCLUSIONS & FINDINGS

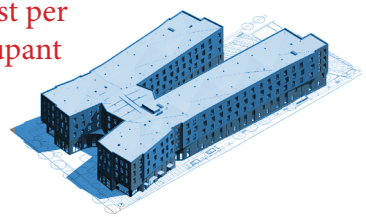




lowest per unit / per bedroom

ARGYLE GARDENS

lowest per occupant

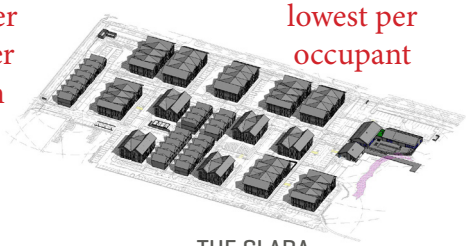


3000 POWELL

lowest per unit / per bedroom

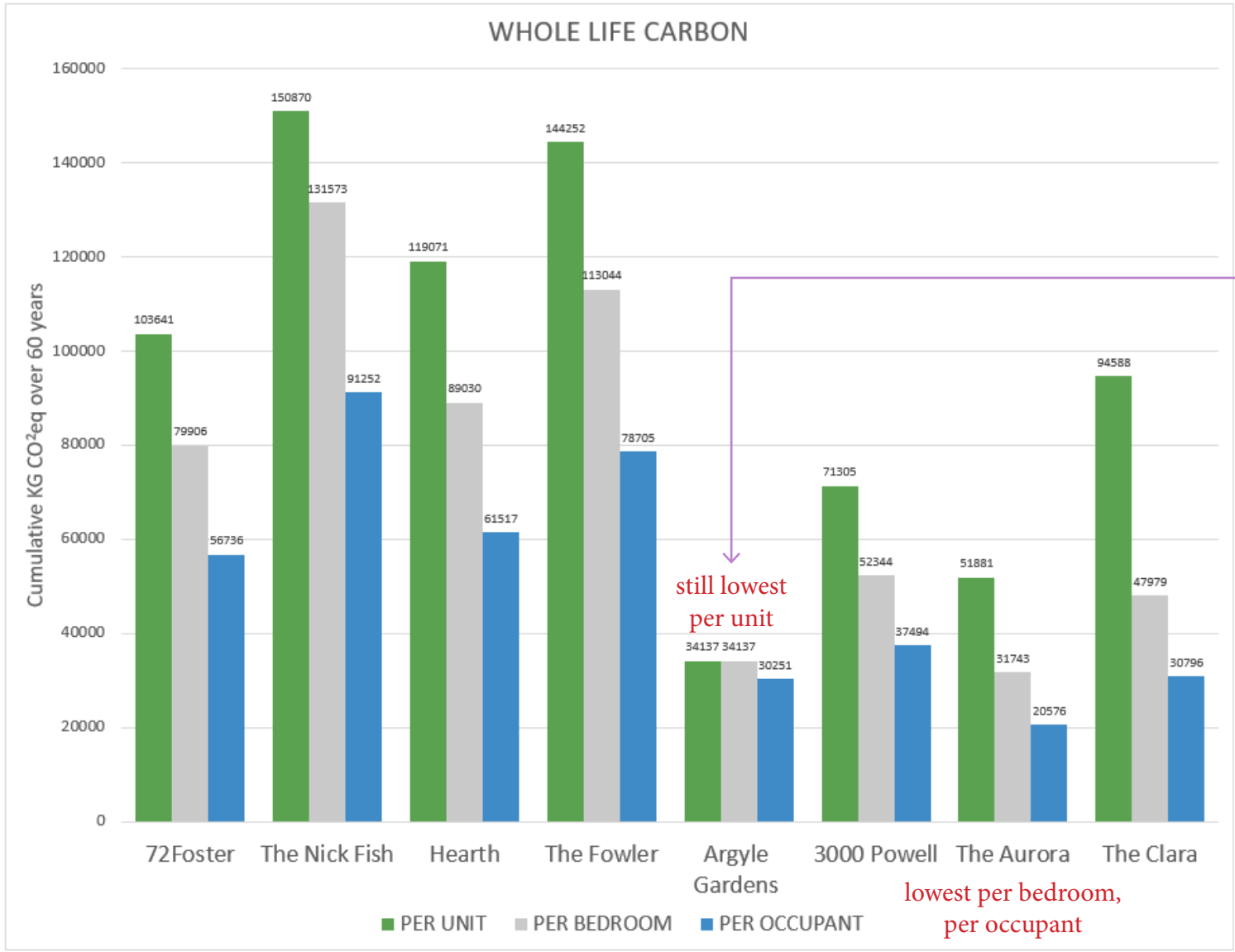
ARGYLE GARDENS

lowest per occupant

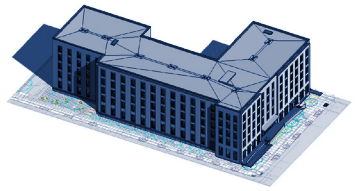


THE CLARA

CONCLUSIONS & FINDINGS

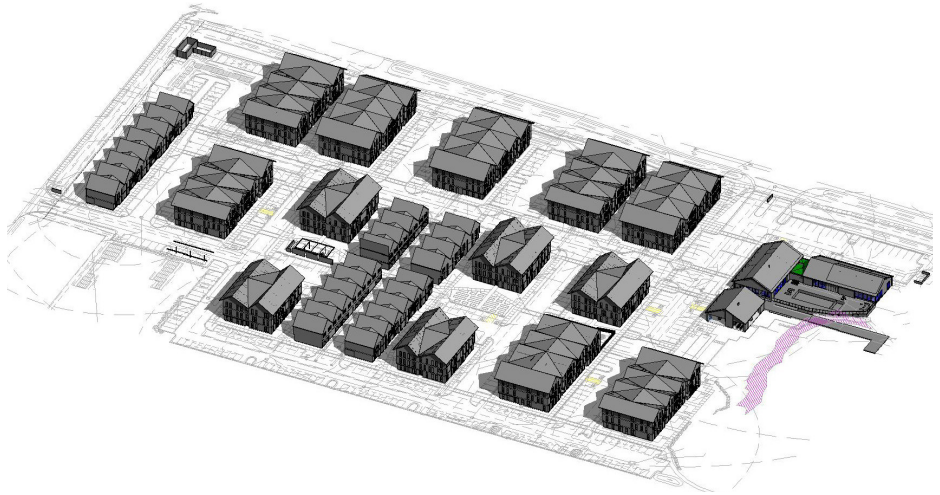


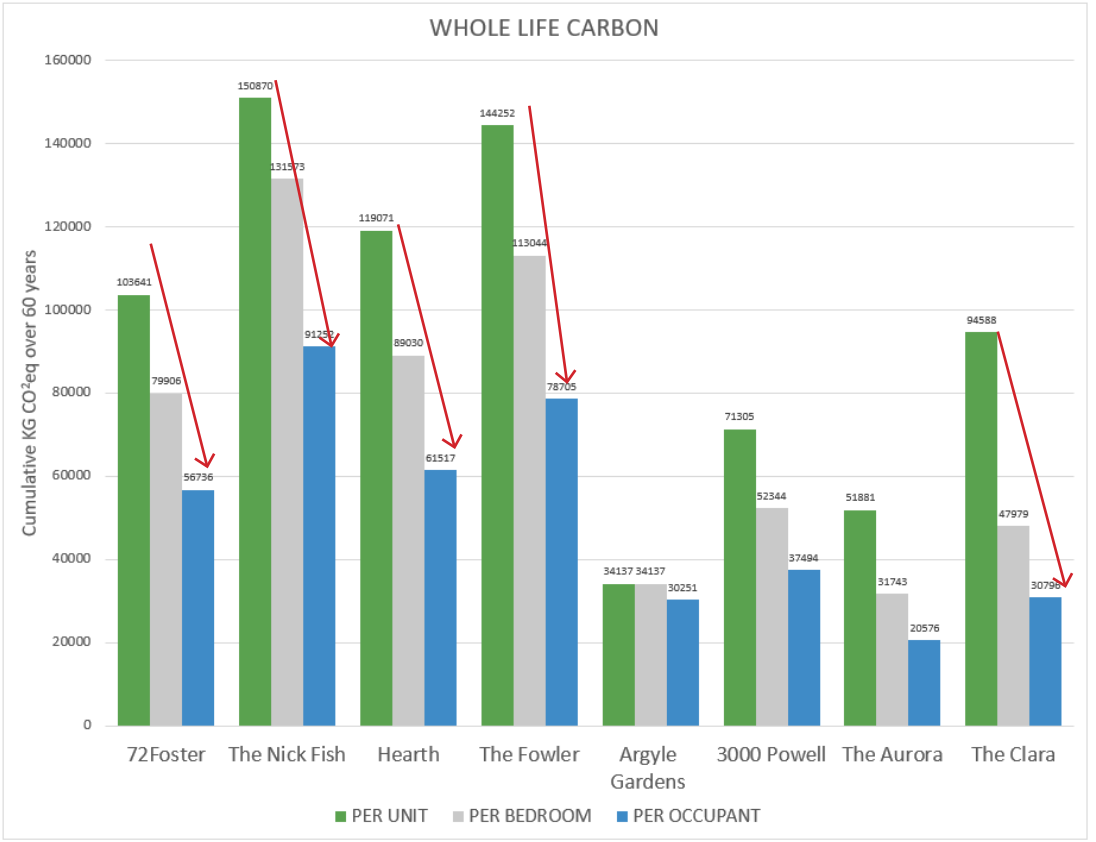
ARGYLE GARDENS



THE AURORA

CONCLUSIONS & FINDINGS





3] **UNITS WITH MULTIPLE BEDROOMS PROVIDE EFFICIENCIES IN EMBODIED/OPERATIONAL CARBON** PER OCCUPANT.

WHY?

- Fewer kitchens, living spaces and bathrooms to build, heat, and cool

CONCLUSIONS & FINDINGS

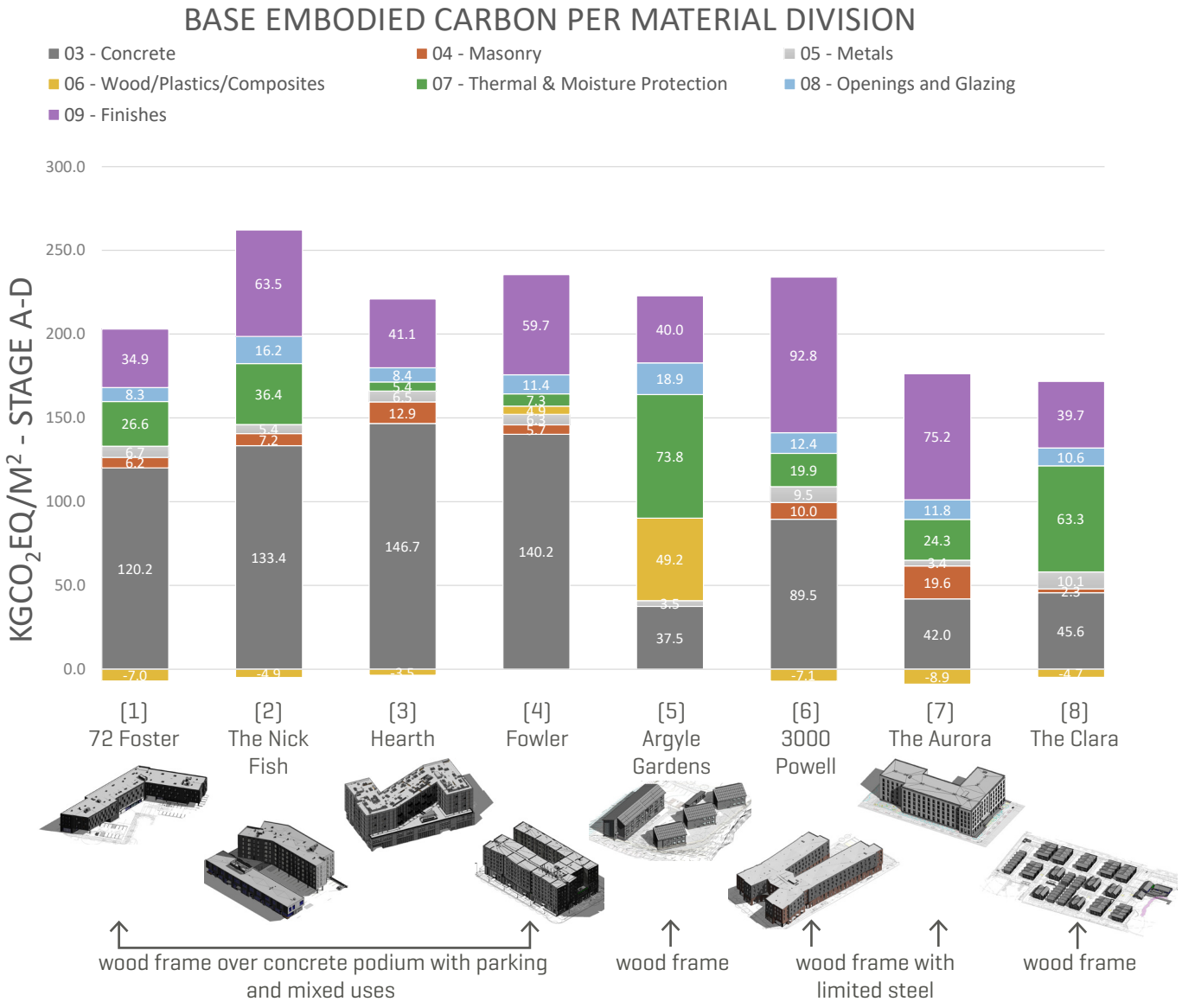
4] FOR CONCRETE PODIUM BUILDINGS, **CONCRETE MAKES UP THE LARGEST % OF EMBODIED CARBON.**

WHY?

- Cement emissions.
- Low carbon concrete not mandated.
- Does not sequester carbon like wood.

RECOMMENDATIONS

- Low carbon concrete should be an embodied carbon priority
- Consider ways to reduce concrete quantity

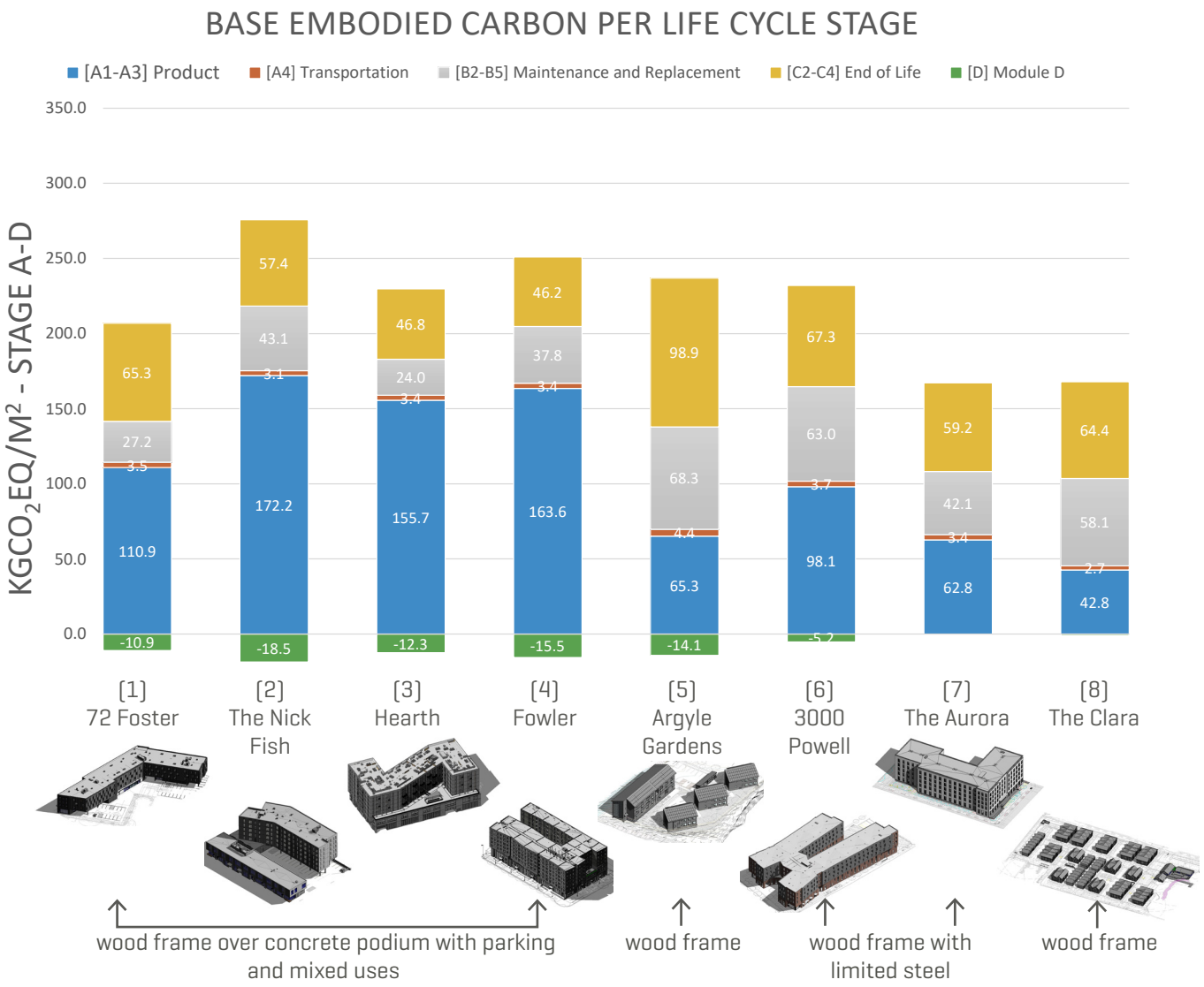


CONCLUSIONS & FINDINGS

5] **WOOD FRAME (INCL. LIMITED STEEL) BUILDINGS** HAVE **HIGHER END-OF-LIFE EMBODIED CARBON** THAN CONCRETE PODIUM BUILDINGS.

WHY?

- Biogenic carbon reduces the initial embodied carbon.
- When biogenic (stored carbon) is included, some of this carbon is re-released at the end-of-life.

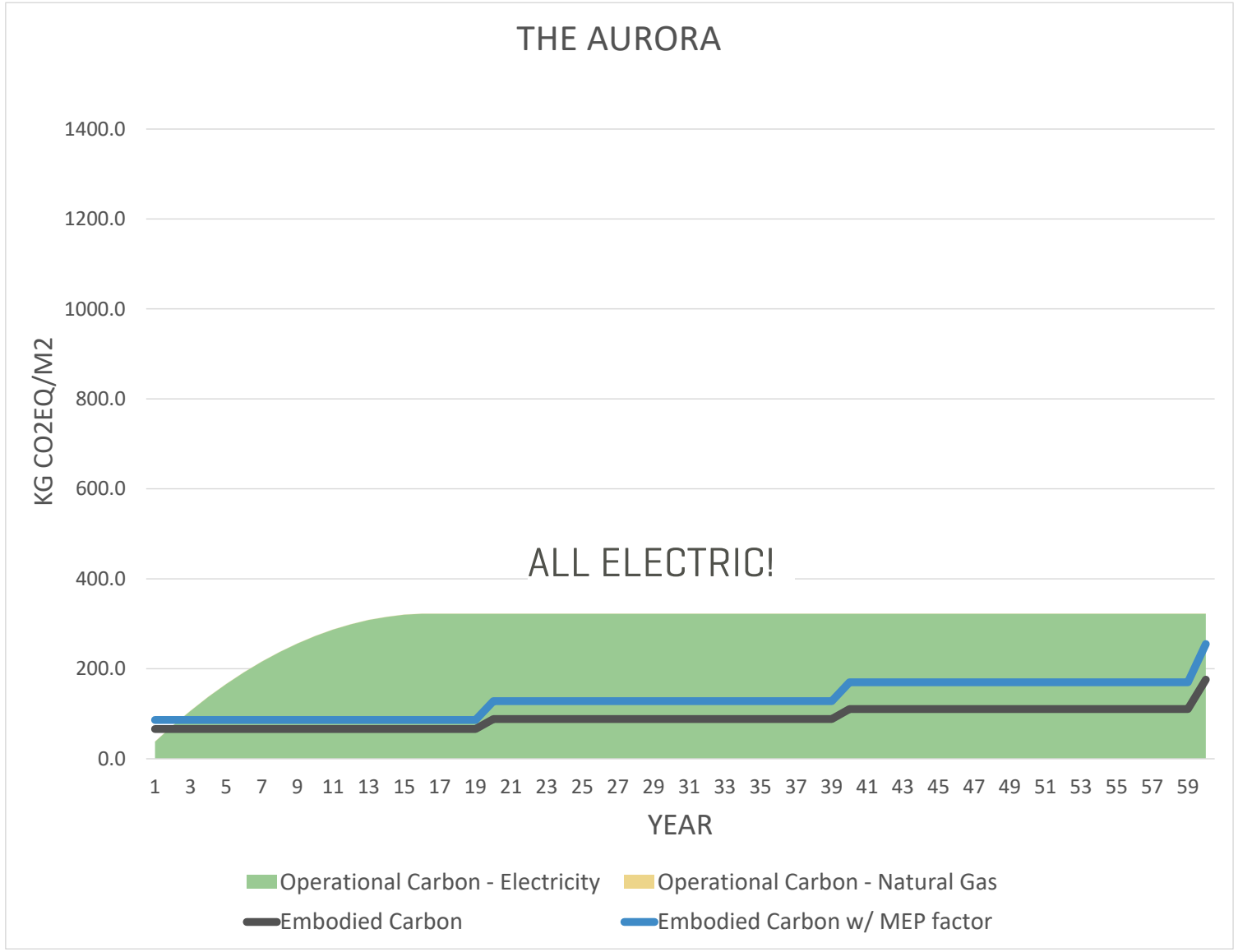


CONCLUSIONS & FINDINGS

6) **THE AURORA,** THE ALL-ELECTRIC PROJECT, WILL HAVE THE LOWEST WHOLE-LIFE CARBON BASED ON CURRENT GRID DECARBONIZATION ASSUMPTIONS.

WHY?

- No operational carbon from natural gas
- Electricity emissions trend towards carbon neutral. *Note that this is a simplification and some operational carbon emissions expected to continue past 2040.
- Based on current assumptions, but it is possible that other projects will electrify their systems as well.



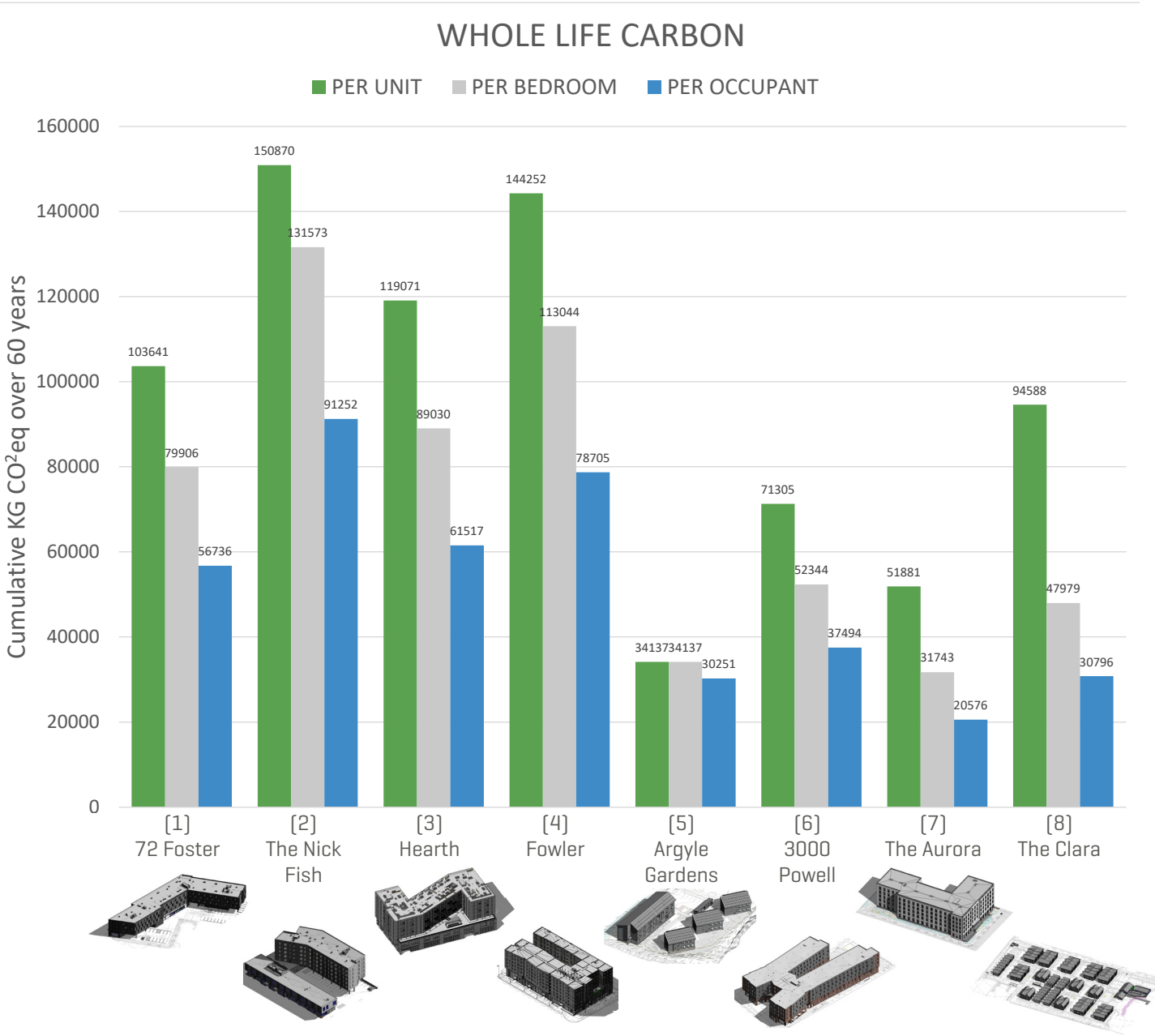
CONCLUSIONS & FINDINGS

7) **CONCRETE PODIUM BUILDINGS HAVE THE HIGHEST WHOLE LIFE CARBON PER UNIT, BEDROOM, AND OCCUPANT...** BUT NOT ALWAYS PER SQUARE METER.

WHY?

- Concrete podium buildings in our study are skewed towards having additional retail or office spaces. This chart does not take into account those uses.

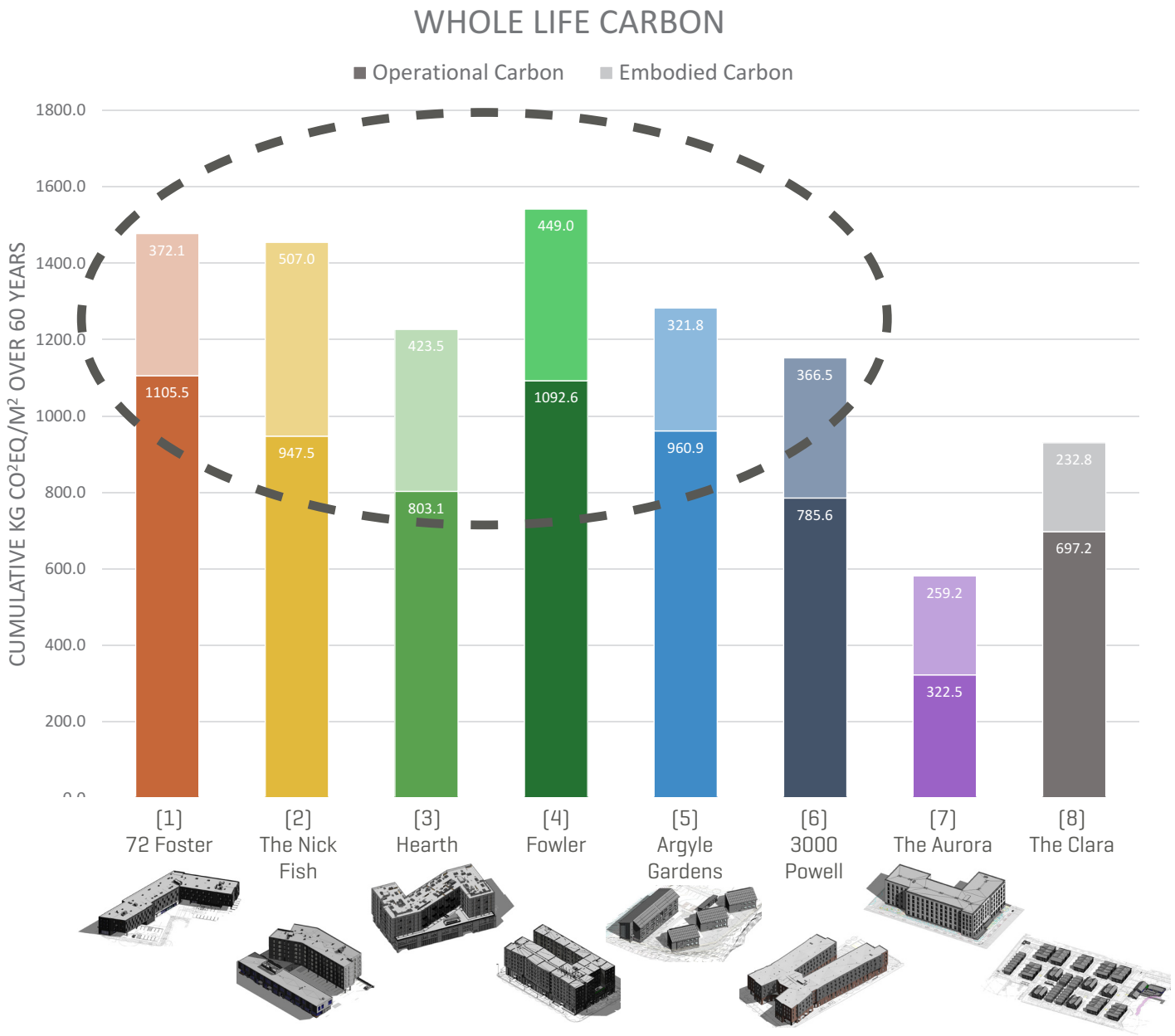
- Concrete allows for higher density and mixed use - it is hard to account for the utility and carbon impact of those benefits.



CONCLUSIONS & FINDINGS

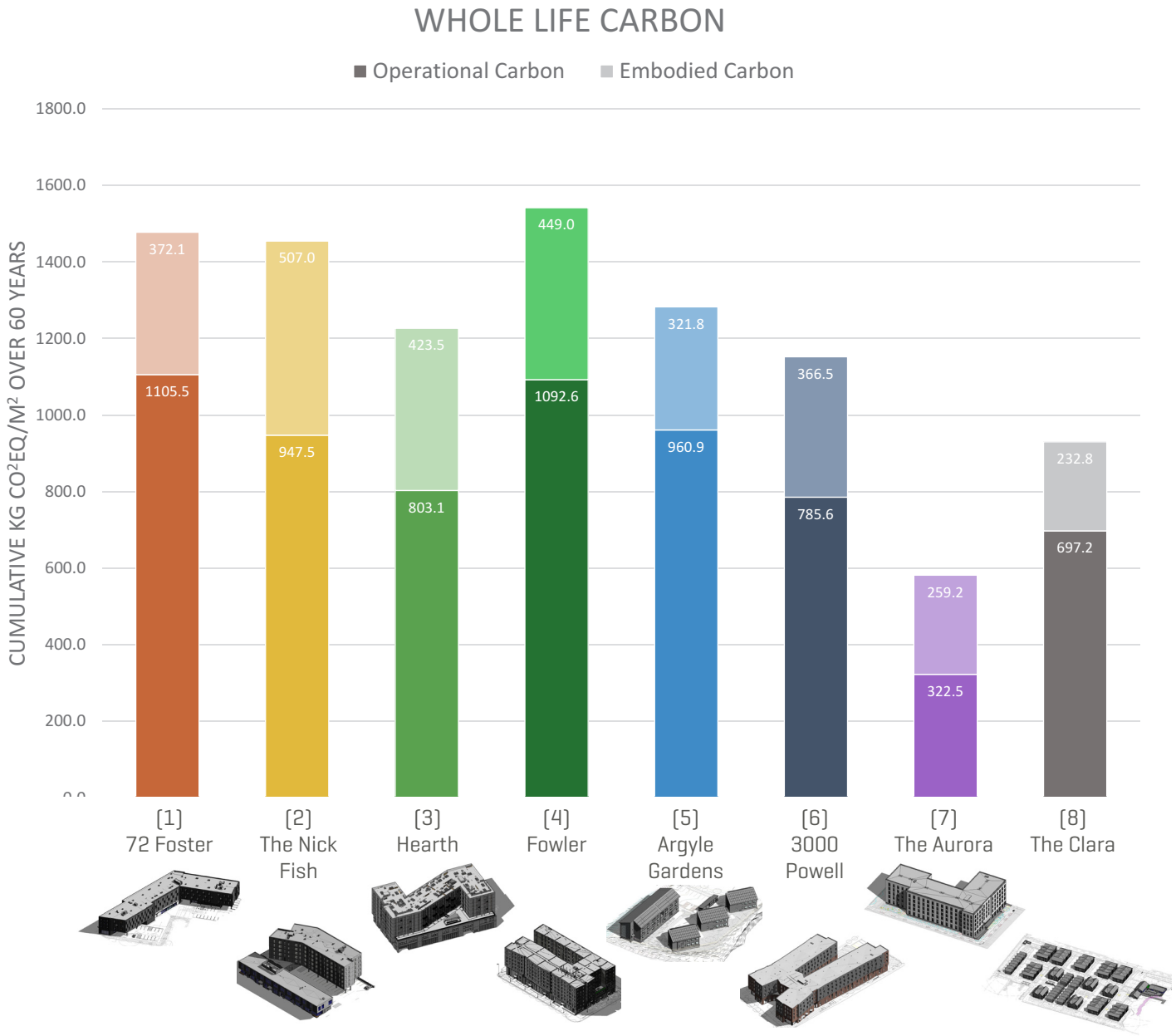
9) **WHOLE LIFE CARBON** FOR SIX OF THE BUILDINGS RANGED FROM 1100 KG CO_2EQ/M^2 TO 1540 KG CO_2EQ/M^2.

- Despite differences in use, size, and building systems, the total whole life carbon per square meter is not as varied as we might expect.
- The Aurora is an outlier due to being all-electric.
- The whole life carbon values are estimates and are not locked in. Building owners could reduce their whole life carbon by upgrading to more efficient systems, extending the building life span, or adding on-site renewable energy.



FINAL THOUGHTS

- SET GOALS FOR EUI, OPERATIONAL CARBON, AND EMBODIED CARBON EARLY IN A PROJECT
- TRACK AGGREGATE ENERGY USAGE DATA AND SETUP FEEDBACK LOOP WITH ARCHITECTS, ENGINEERS, AND OWNERS
- REQUEST EMBODIED CARBON DATA FROM MEP MANUFACTURERS
- THE MOST SUSTAINABLE BUILDING IS THE ONE THAT IS ALREADY BUILT



QUESTIONS?

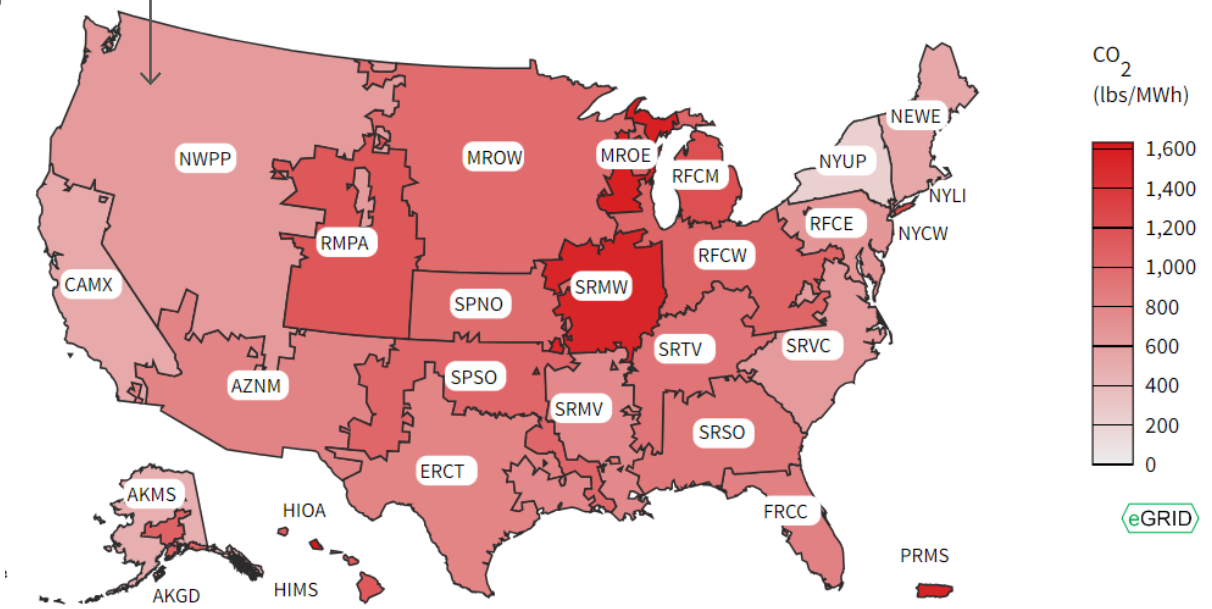
OPERATIONAL CARBON METHODOLOGY SOURCE OPERATIONAL CARBON INTENSITY

IDAHO POWER (ONTARIO, OR & BOISE, ID)
886 lbs / MWh[2]

PORTLAND GENERAL ELECTRIC (PGE) (PORTLAND)
705.5 lbs / MWh[3]

CITY OF ASHLAND ELECTRIC DEPARTMENT (MEDFORD, OR)
65 lbs / MWh[4]

WESTERN POWER POOL (FORMERLY NWPP)
638.5 lbs CO_2eq / MWh



EMISSIONS RATE MAP[1]

1 https://www.epa.gov/egrid/power-profiler#/

2 2021 & 2022 average, https://www.idahopower.com/energy-environment/energy/energy-sources/our-path-away-from-coal/

3 Includes purchased and generated energy. Portland General Electric. "2021 ESG Report: Advancing Our Clean Energy Future," 2021. https://assets.ctfassets.net/416ywc1laqmd/5aLMRJup0FHiMTf0EpgzYO/9e384dc5c6422147ddadbd821913163a/PGE_ESG21_Web.pdf.

4 Energy purchased from BPA, includes direct and indirect emissions. Source: DEQ. "Oregon Clean Fuels Program: Updated Electricity Carbon Intensity Values for 2021," 2021. https://www.oregon.gov/deq/ghgp/Documents/cfpUpdated2021CIs.pdf