A predictive pyrolysis life cycle assessment tool

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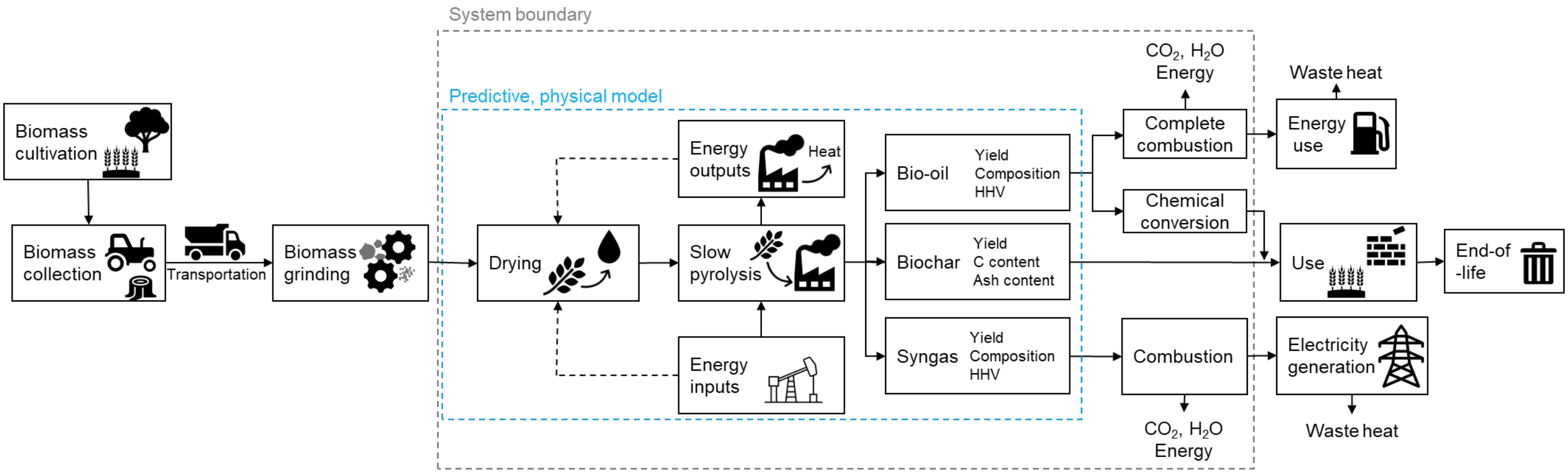
Goal

- Simple and approachable model of pyrolysis outcomes and environmental impacts
- Minimize user inputs
- No proprietary software
- Adaptable to a wide range of feedstocks, pyrolysis conditions, and applications

Scope



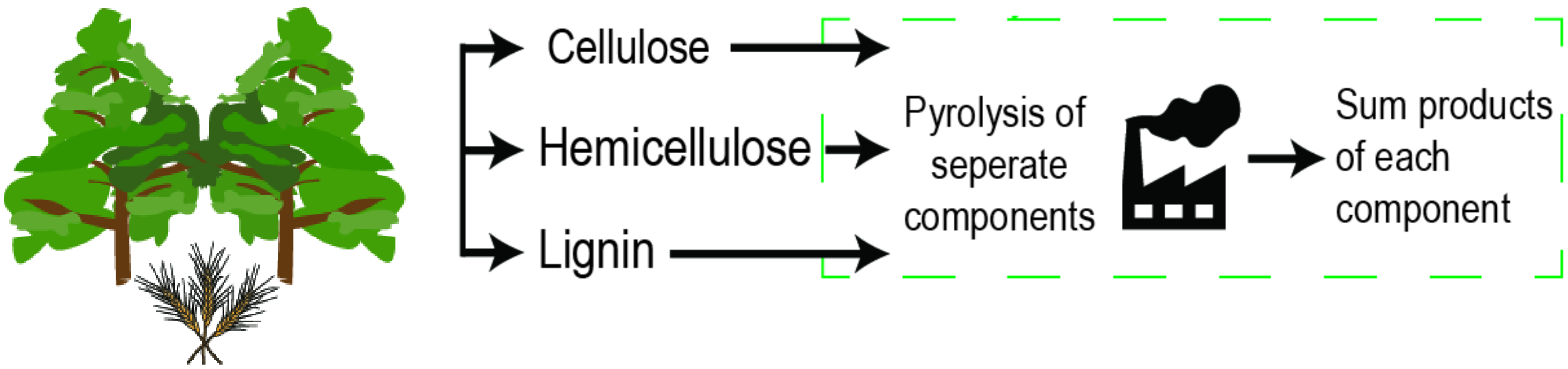
- Only models pyrolysis process itself – need additional data for downstream and upstream processes for a complete life-cycle assessment
- Focused on greenhouse gas emissions, biochar properties, and energy inputs and outputs
- Adaptable!

Approach

"Three-parallel reactions model"

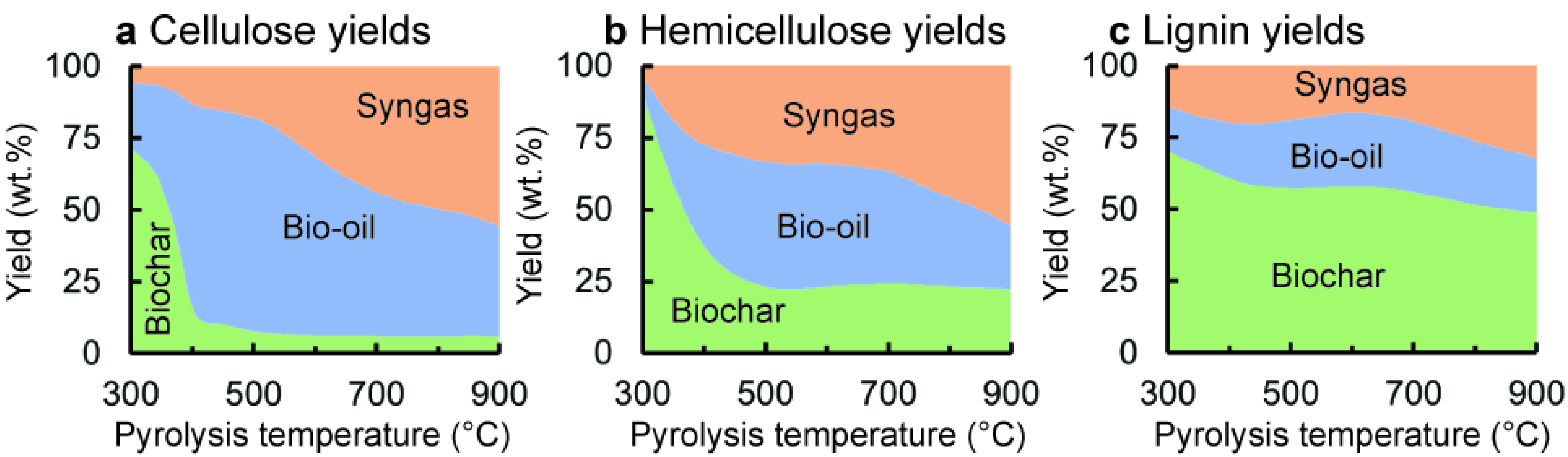
Model cellulose, hemicellulose, lignin pyrolysis separately – additively combine

Lignocellulose biomass

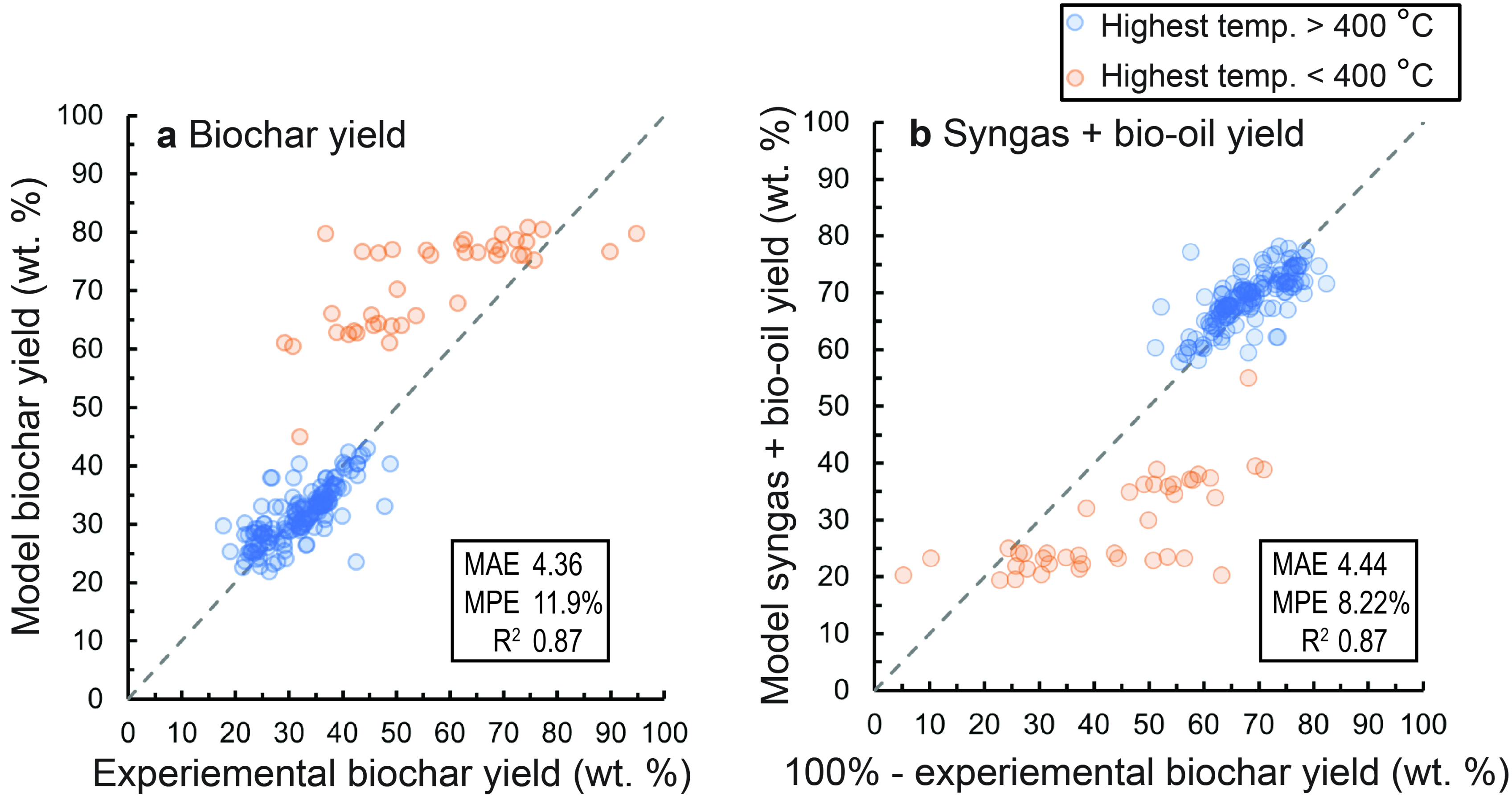


Approach

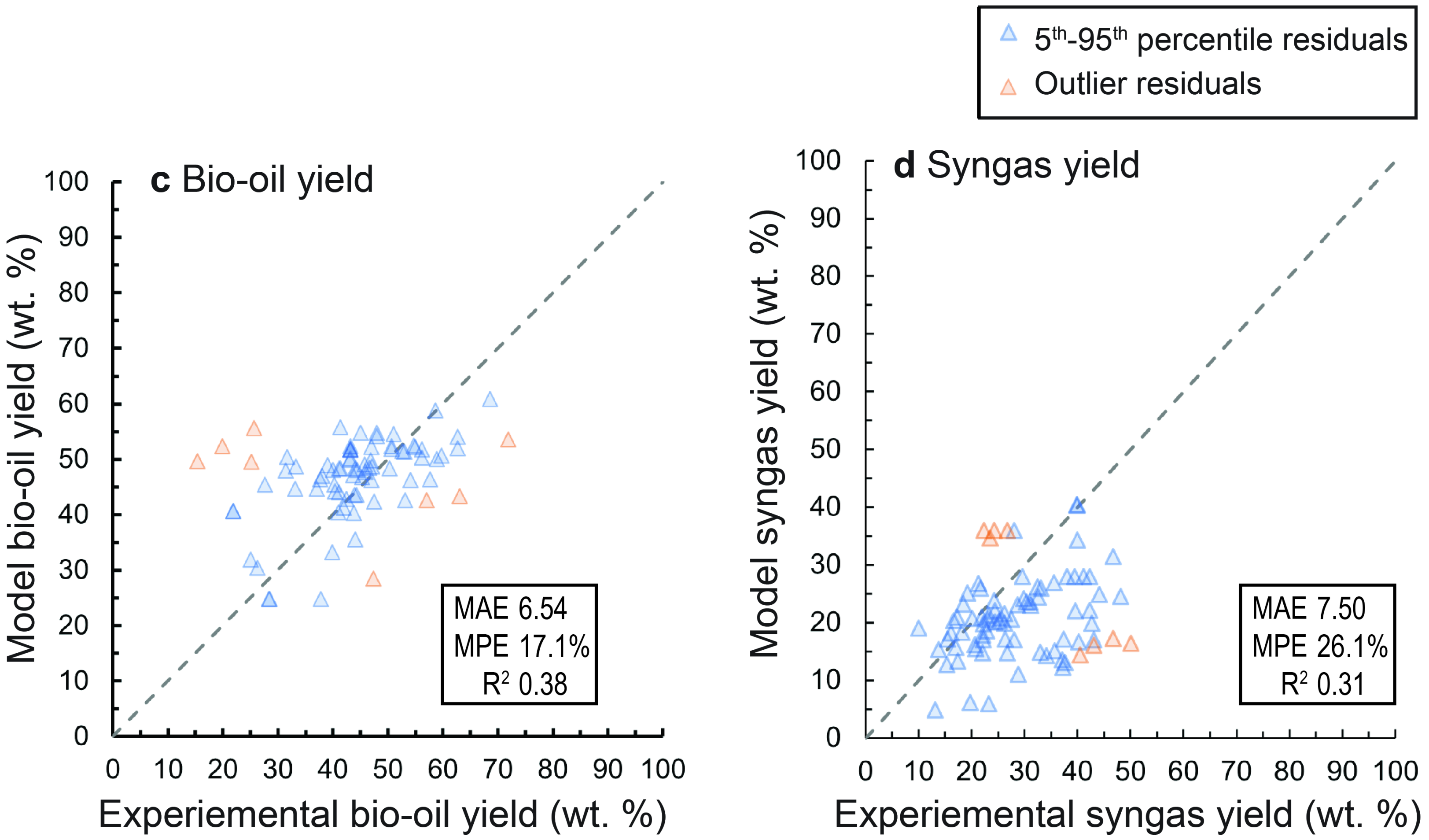
- Use known experimental data for cellulose, hemicellulose, and lignin pyrolysis outcomes
- Model biochar, bio-oil, and syngas composition
- Biochar atomic composition, syngas molecular composition, bio-oil atomic composition and HHV
- Reaction energy requirement modeled as enthalpy balance



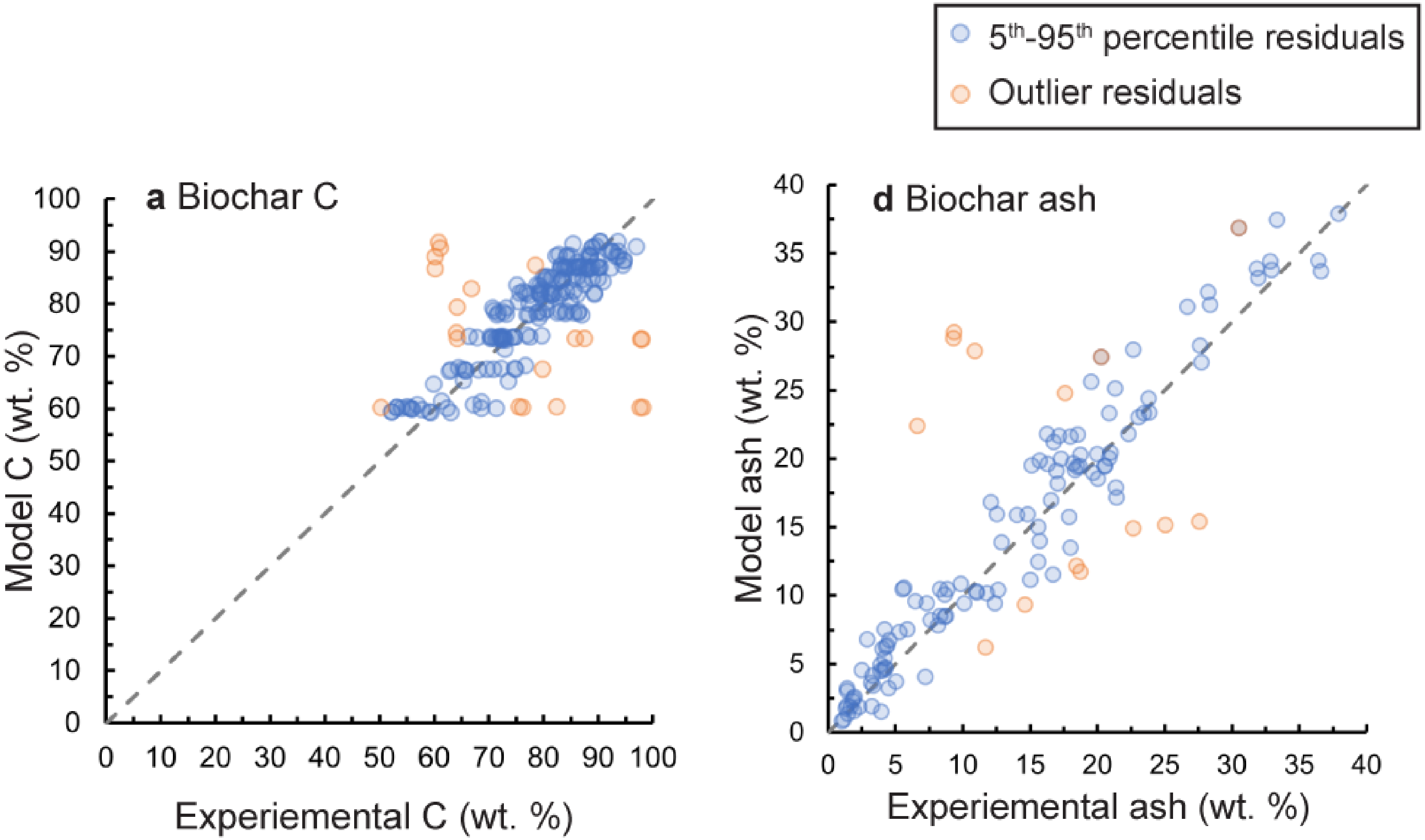
Model validation



Model validation

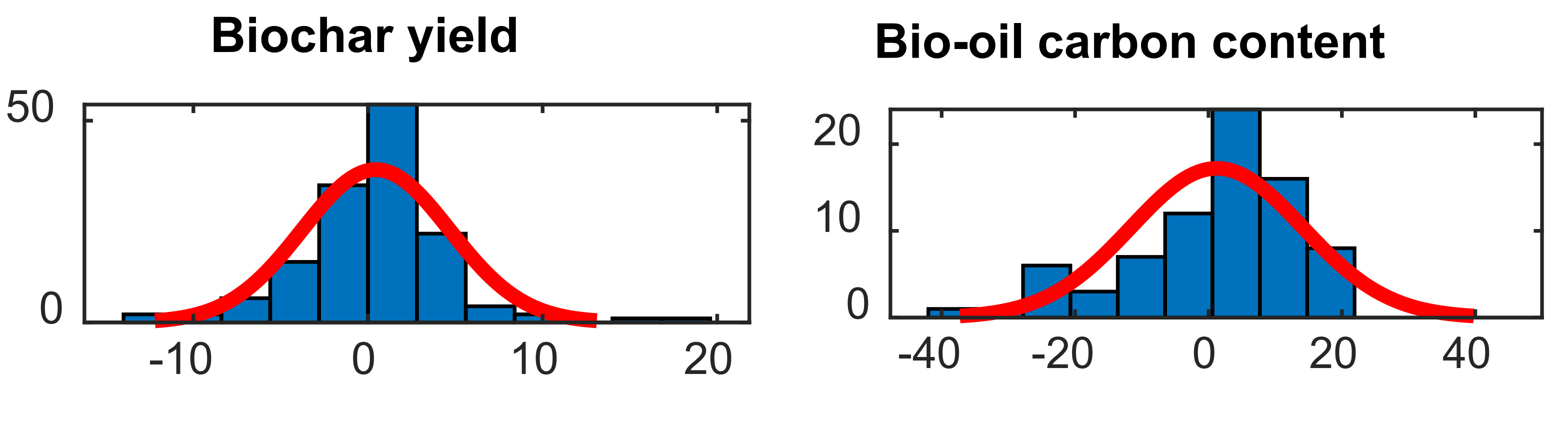


Model validation

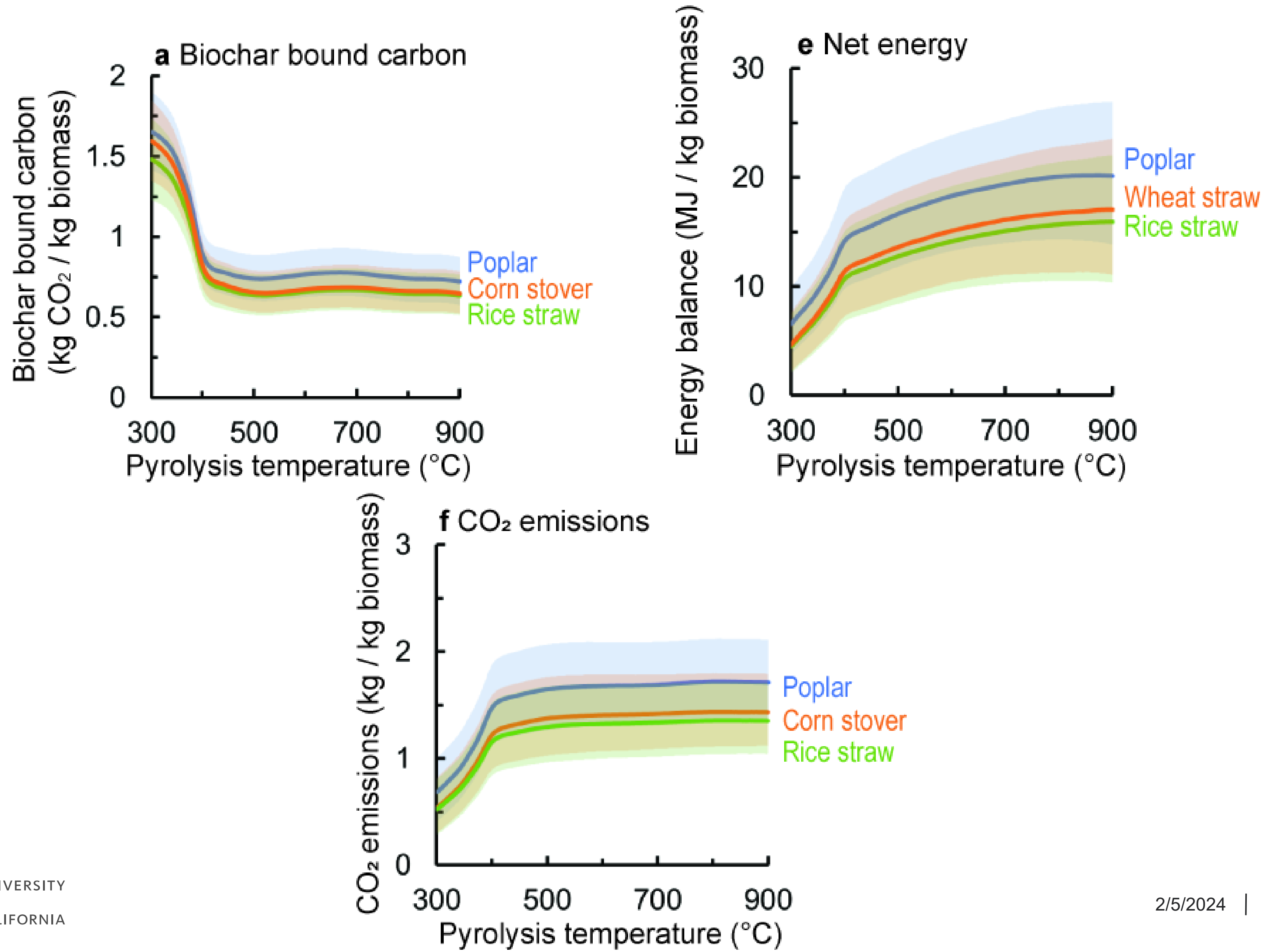


Model uncertainty

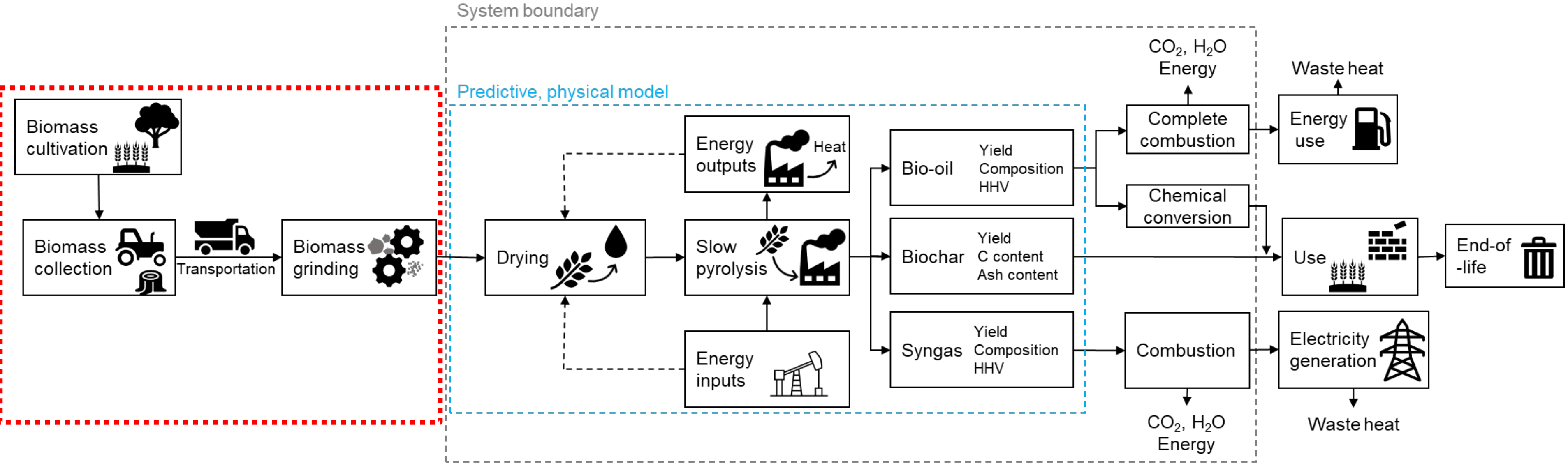
- Incorporate model uncertainty as distributions of validation data residuals as inputs for Monte Carlo simulations
- Just uncertainty due to model assumptions – not other factors



Model results

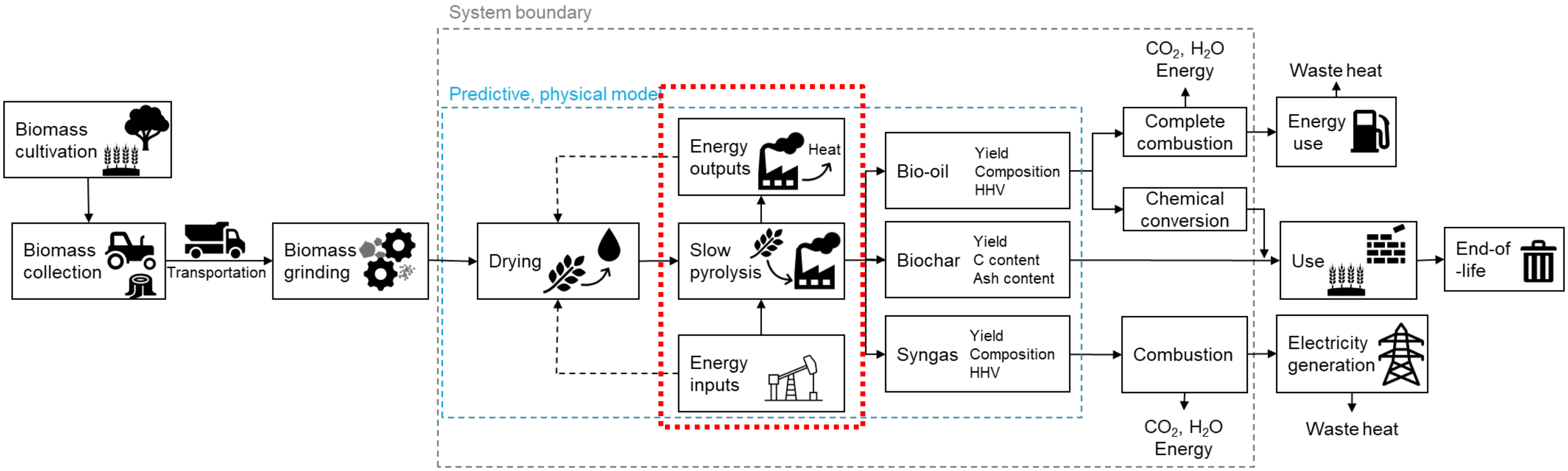


Application to life cycle assessment



- Upstream data – incorporate from existing LCA data
- Applicable to both primary crop production and waste residues
- Can apply scenario specific transportation
- Biomass grinding can be modeled with existing inventories or models

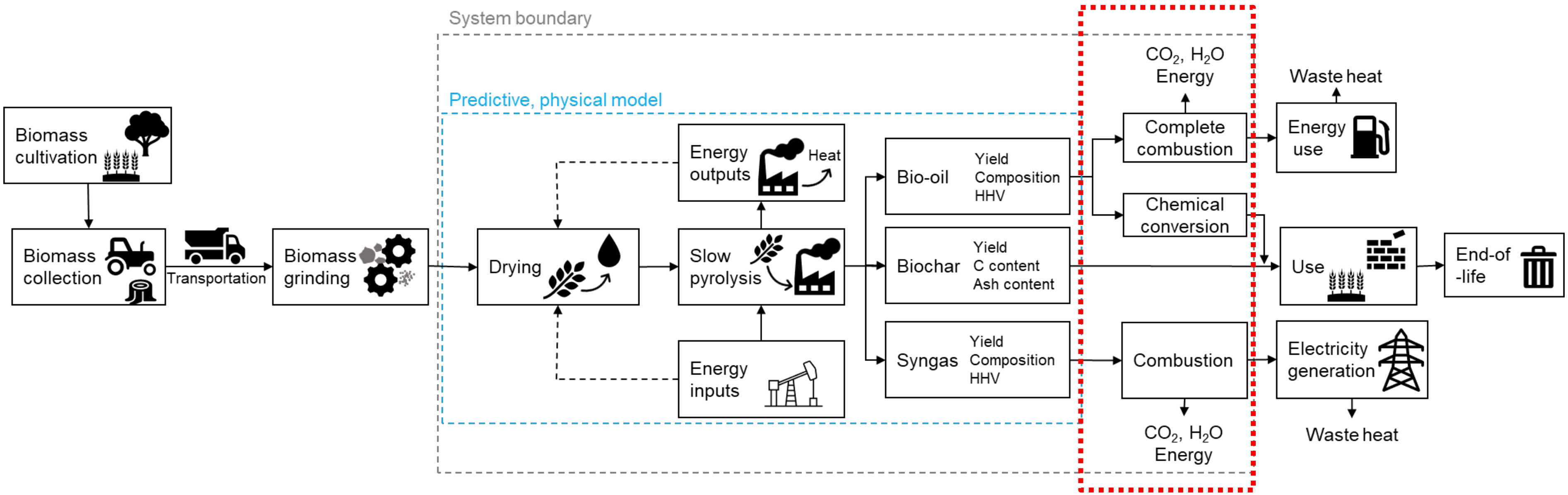
Application to life cycle assessment



- Include thermal efficiency of specific pyrolysis system
- e.g., 90% (Liao et al., 2020)
- Exact system design (e.g., heating rate) effects excluded.

Liao, M., Kelley, S., Yao, Y., 2020. ACS Sustainable Chem. Eng. 8, 1252–1261. doi.org/10.1021/acssuschemeng.9b06522

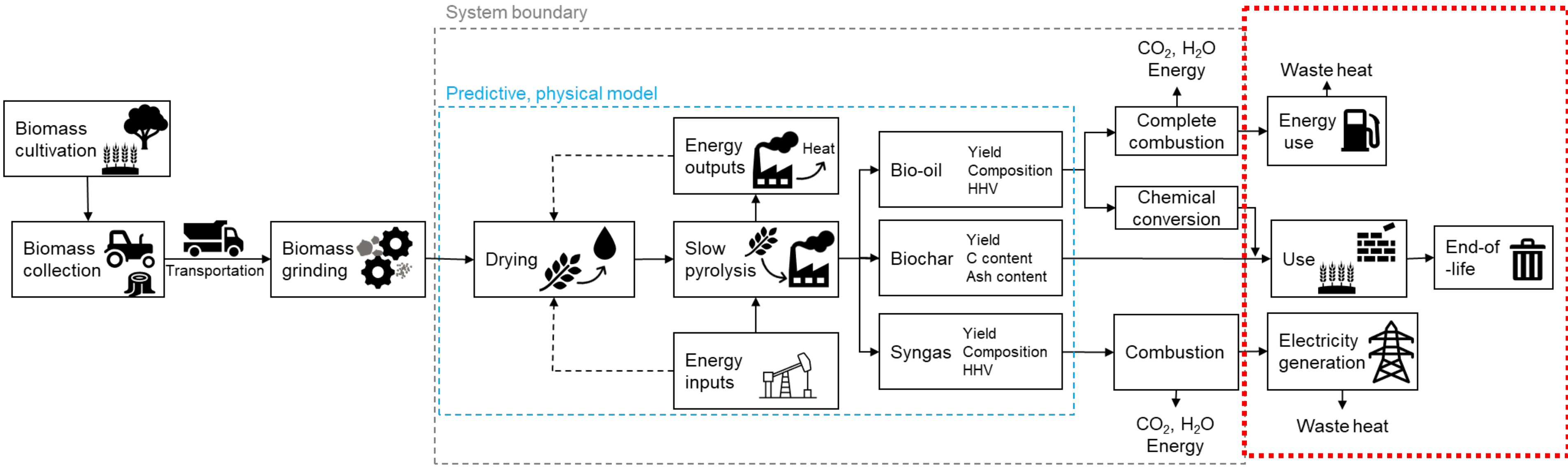
Application to life cycle assessment



- Emissions other than CO_2, and pyrolysis outputs not modeled
- Other emissions (CO, SO_2, NO_2, NO, etc.) adapted from proxy inventory for pyrolysis of poplar at 500 °C (Peters et al., 2015)

Peters, J.F., Iribarren, D., Dufour, J., 2015. Environmental Science and Technology 49, 5195–5202. doi.org/10.1021/ES5060786

Application to life cycle assessment



Out of scope, apply existing data:

- Thermal efficiency of combustion processes
- Inputs to refine bio-oil
- Application of biochar, degradation over time

Case studies

Small scale (individual farm)

Large scale (guide policy)

Case studies: small scale

Feeder Creek Farm

10-acre organic fruit and
vegetable farm in Bozeman, MT

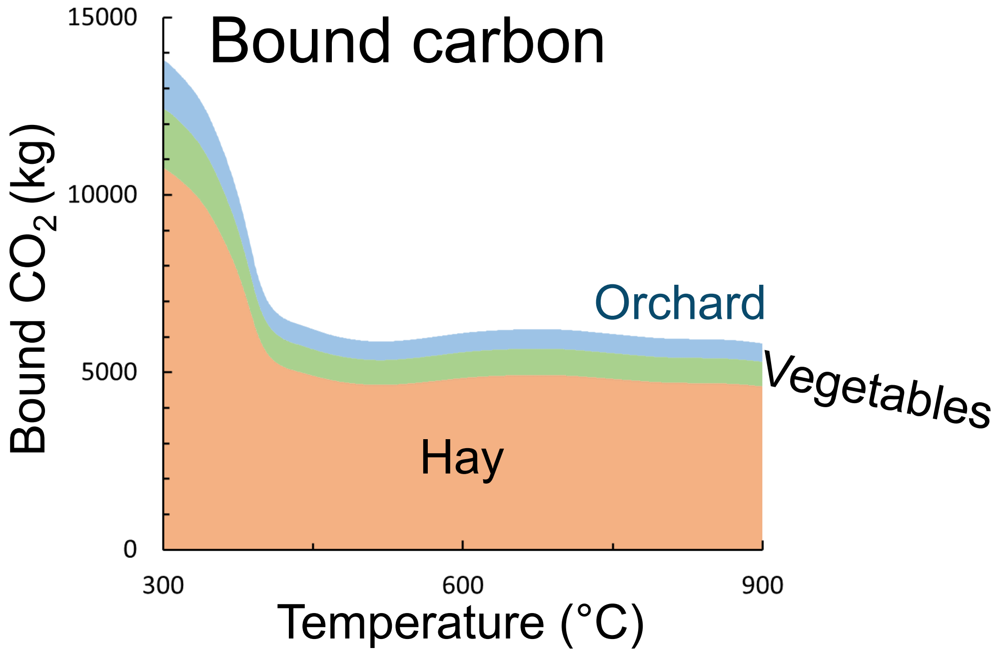
Currently makes biochar for soil
amendment from crop residues
with a simple retort kiln

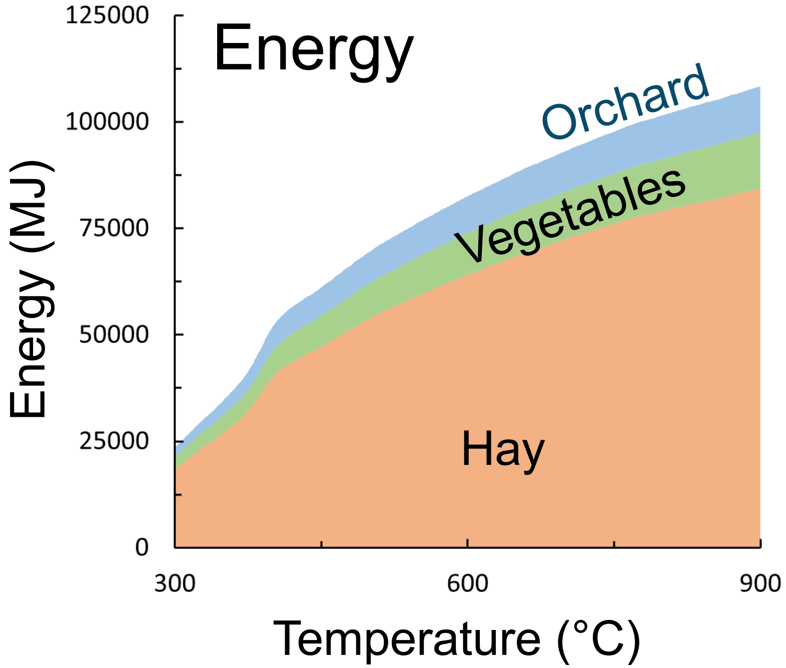
Inform benefits of a more
expensive but more efficient system

Case studies: small scale

5 acres hay, 1.5 acres vegetables, 1.5 acres orchard

Residues only, 30% of hay and vegetable residues left on field

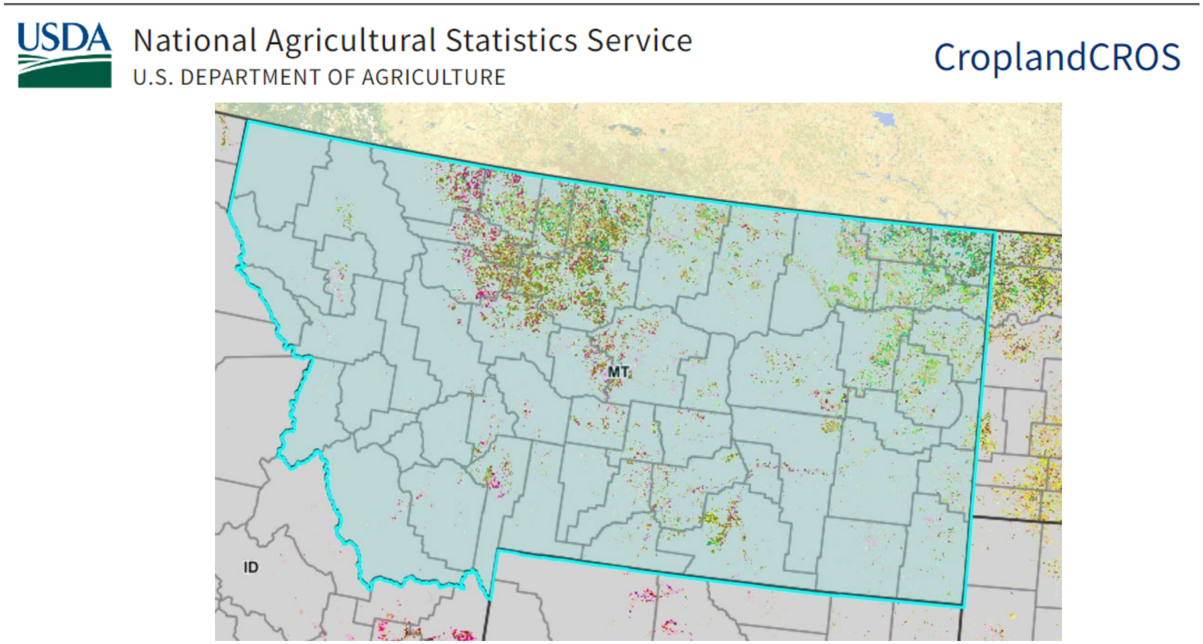


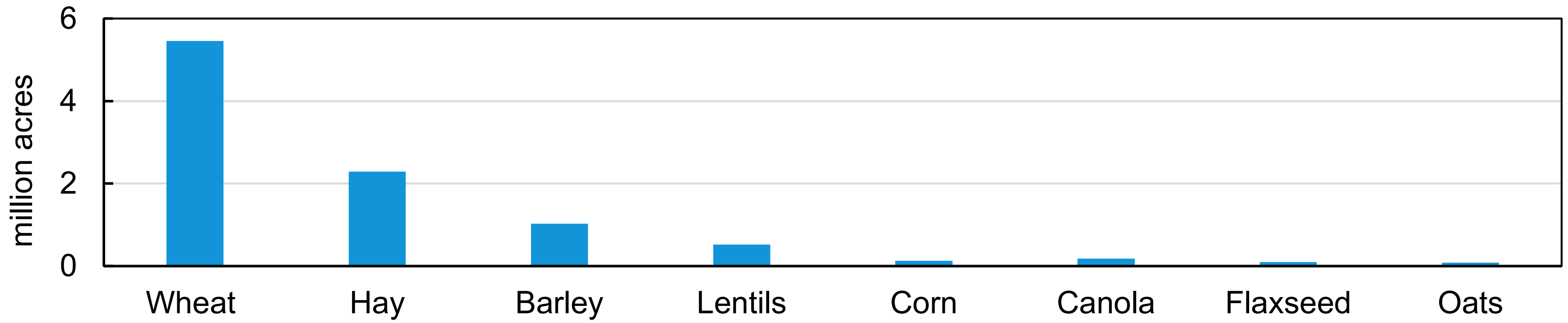


Case studies: large scale

Inform policy

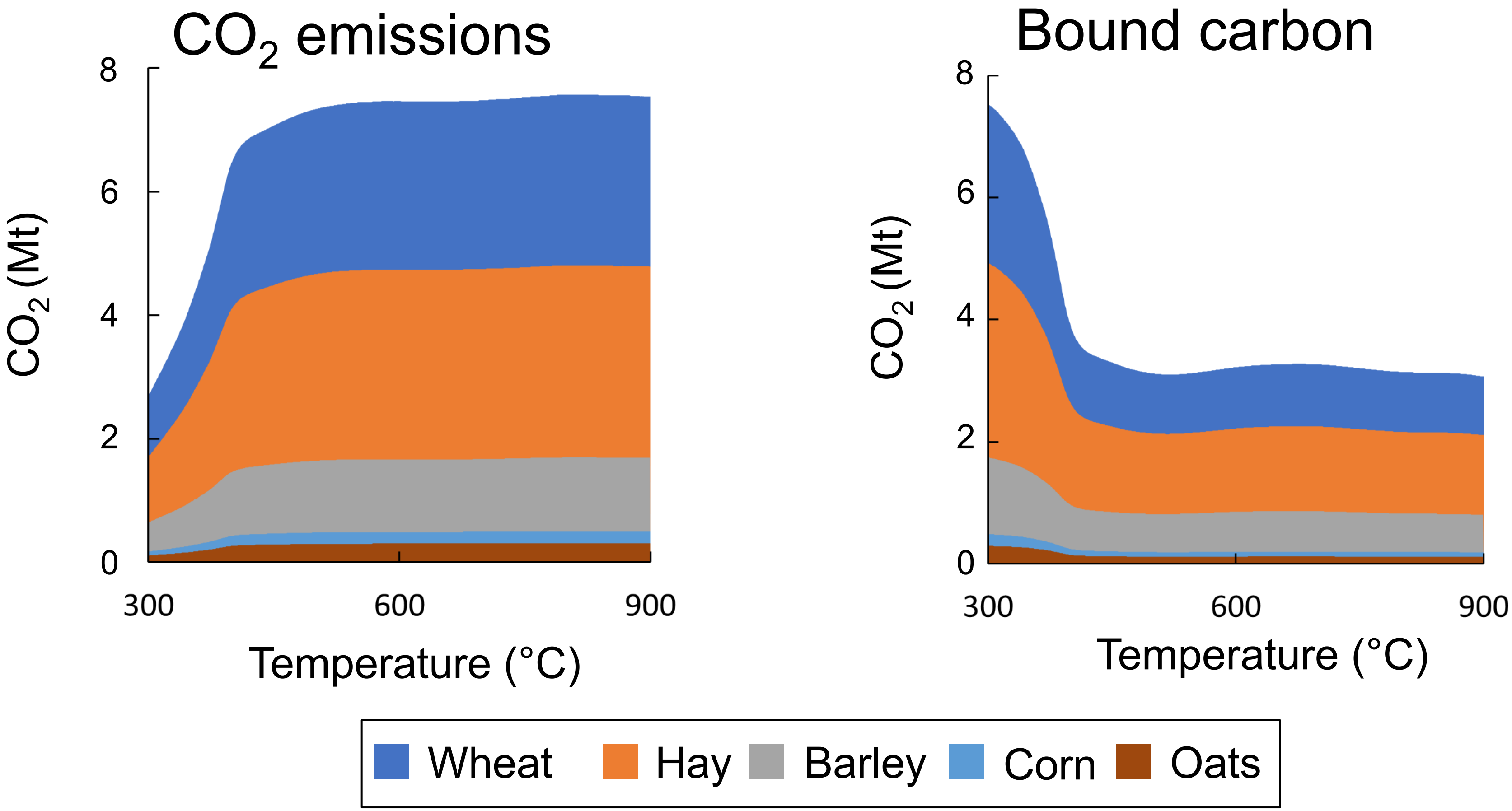
e.g., availability of agricultural residues





Case studies: large scale

Total residue utilization potential



Take aways

Developed tool can accurately determine biochar yields and properties

- More uncertainty for syngas and bio-oil

Tool fills key life-cycle inventory data gaps for pyrolysis

Broadly applicable for data-poor systems, both large and small scale

Thank you!

Questions?

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Developed tool

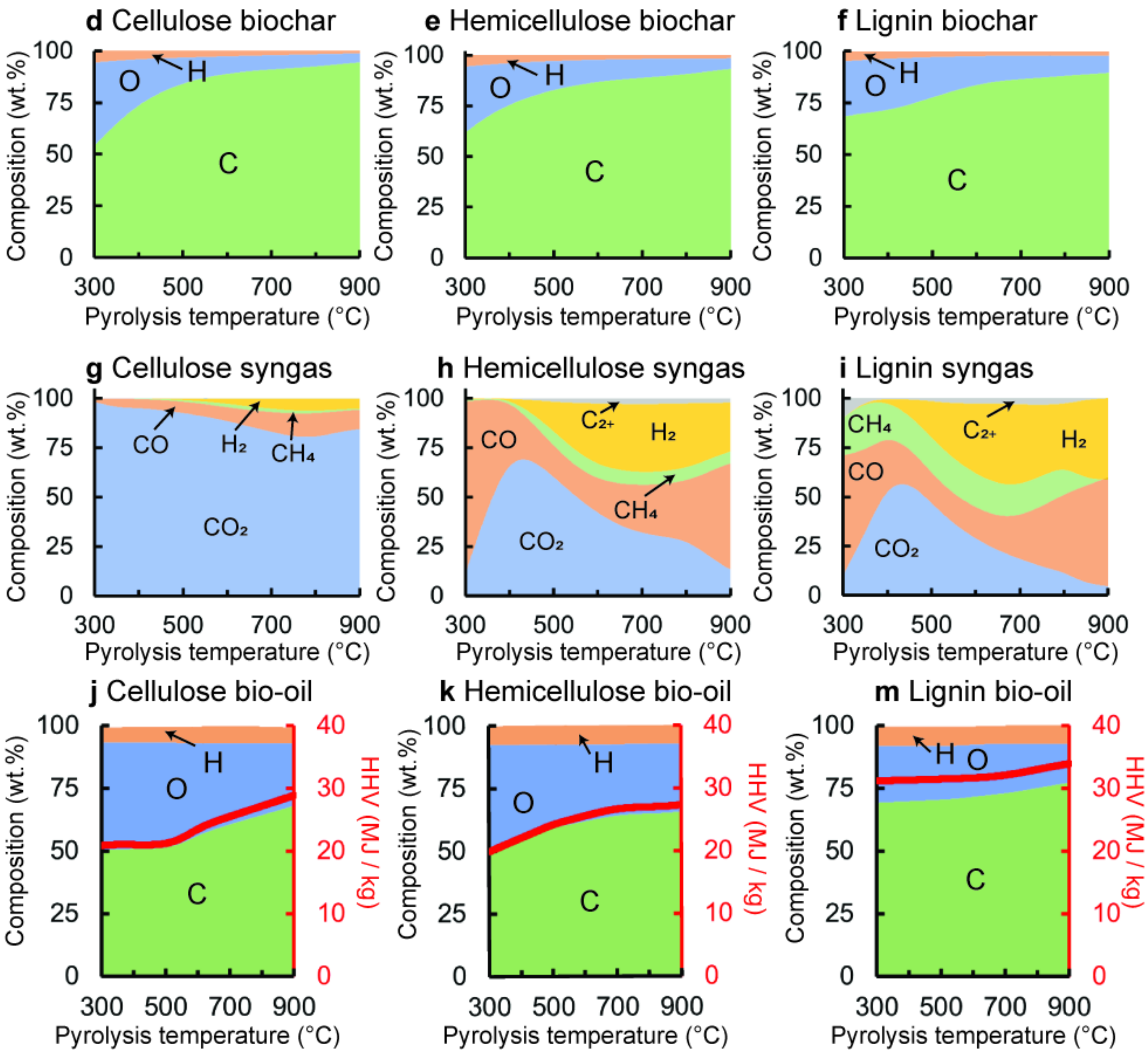
Feedstock content	Wt. %
Cellulose (dry basis)	0
Hemicellulose (dry basis)	5
Lignin (dry basis)	90
Ash (dry basis)	5
Moisture content (% of dry mass)	50
	°C
Pyrolysis temperature	900
Valid for 300-900 °C, integers only	
Scenario selection	
Feedstock drying scenario (select from drop down)	Natural gas
Bio-Oil application scenario (select from drop down)	Combustion

Developed tool

Biochar Product				
	Direct output	Uncertainty median	Uncertainty -stdev	Uncertainty +stdev
Biochar Yield (Wt. % of dry biomass)	**50.05**	50.50	46.29	54.72
Biochar Carbon (Wt. % of biochar)	**80.13**	80.06	71.88	88.24
Biochar Hydrogen (Wt. % of biochar)	**1.90**	1.97	0.75	3.19
Biochar Oxygen (Wt. % of biochar)	**7.98**	7.45	1.70	13.72
Biochar ash (Wt. % of biochar)	**9.99**	8.96	4.60	13.32
Biochar bound carbon (kg CO2 / kg biomass)	**1.47**	1.48	1.35	1.62

Life Cycle Inventory			
	Direct output	**Uncertainty median**	**Source and notes**
Feedstock input (kg)	1.00	1.00	Functional unit.
Biochar product (kg)	0.50	0.51	Developed model.
Biochar product bound carbon (kg CO2)	1.47	1.48	Developed model.
Net energy product (MJ)	5.70	9.37	Developed model. Includes potential use of natural gas in feedstock drying.
Bio-oil product (kg)	0.00	0.00	Developed model. Zero if bio-oil combustion scenario is selected.
Bio-oil product bound carbon (kg CO2)	0.00	0.00	Developed model. Zero if bio-oil combustion scenario is selected.
CO_2 (kg)	0.95	1.80	Developed model.
CO (μg)	0.15	0.15	Peters et al., corrected for modeled yield.

Additional results



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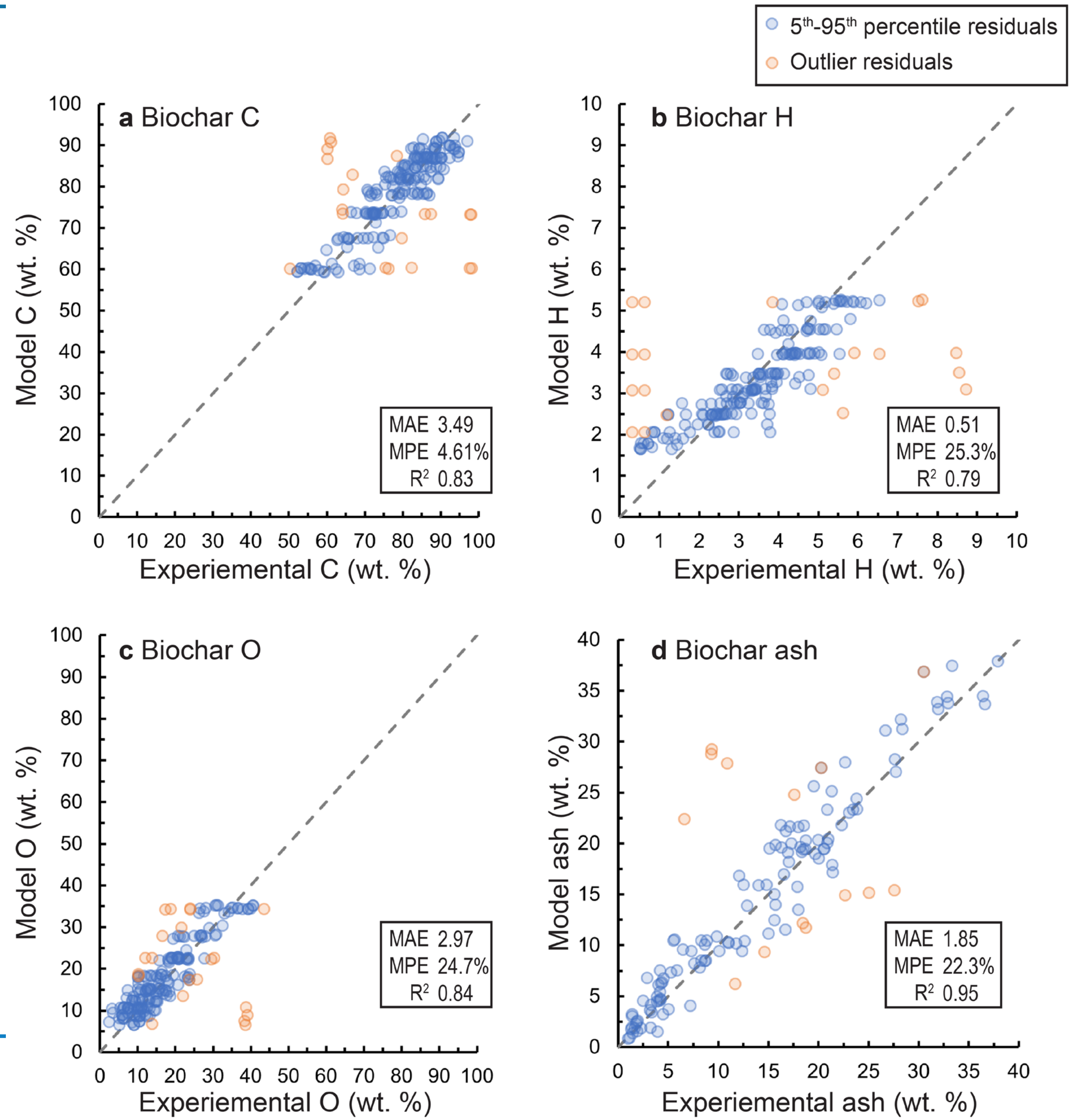

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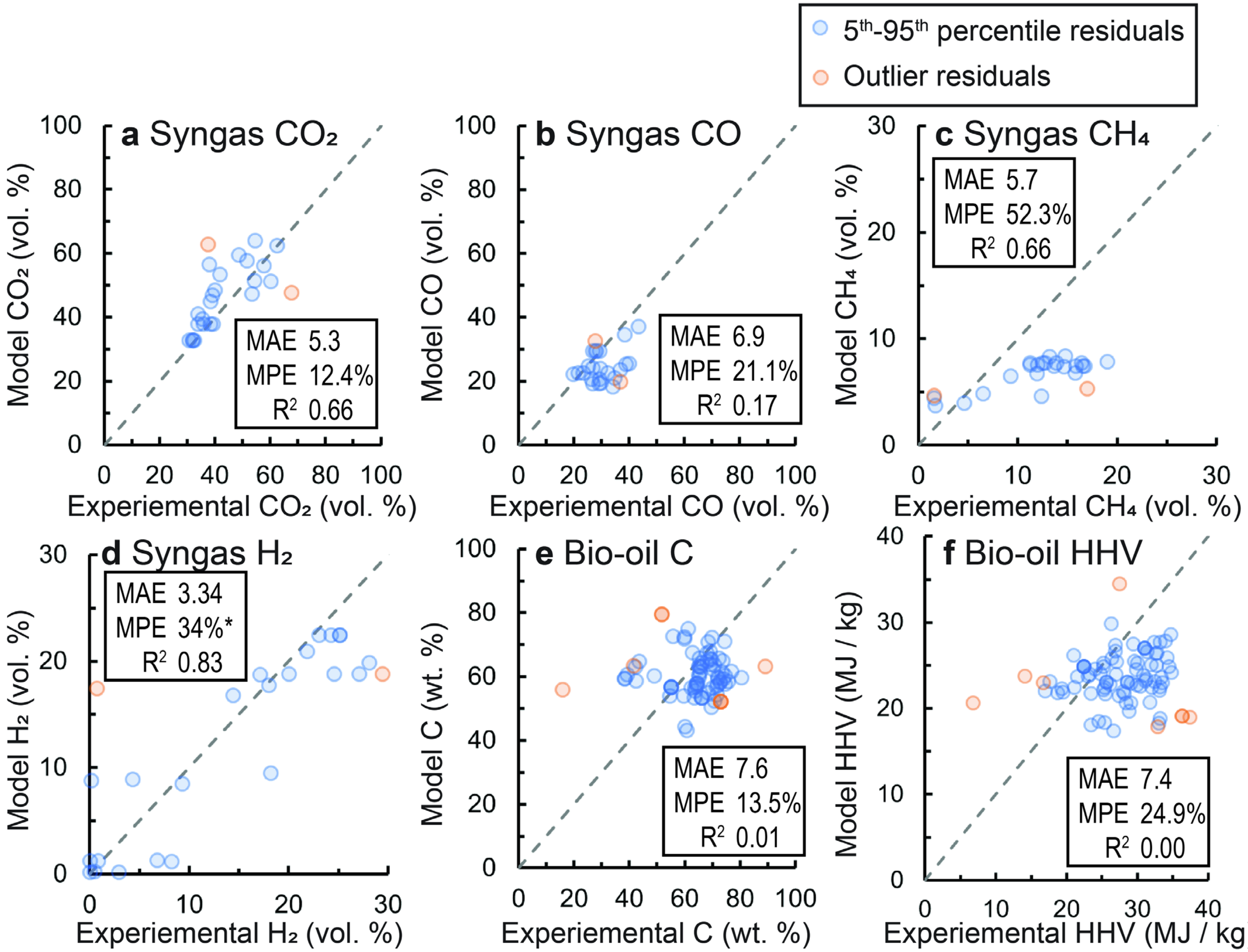

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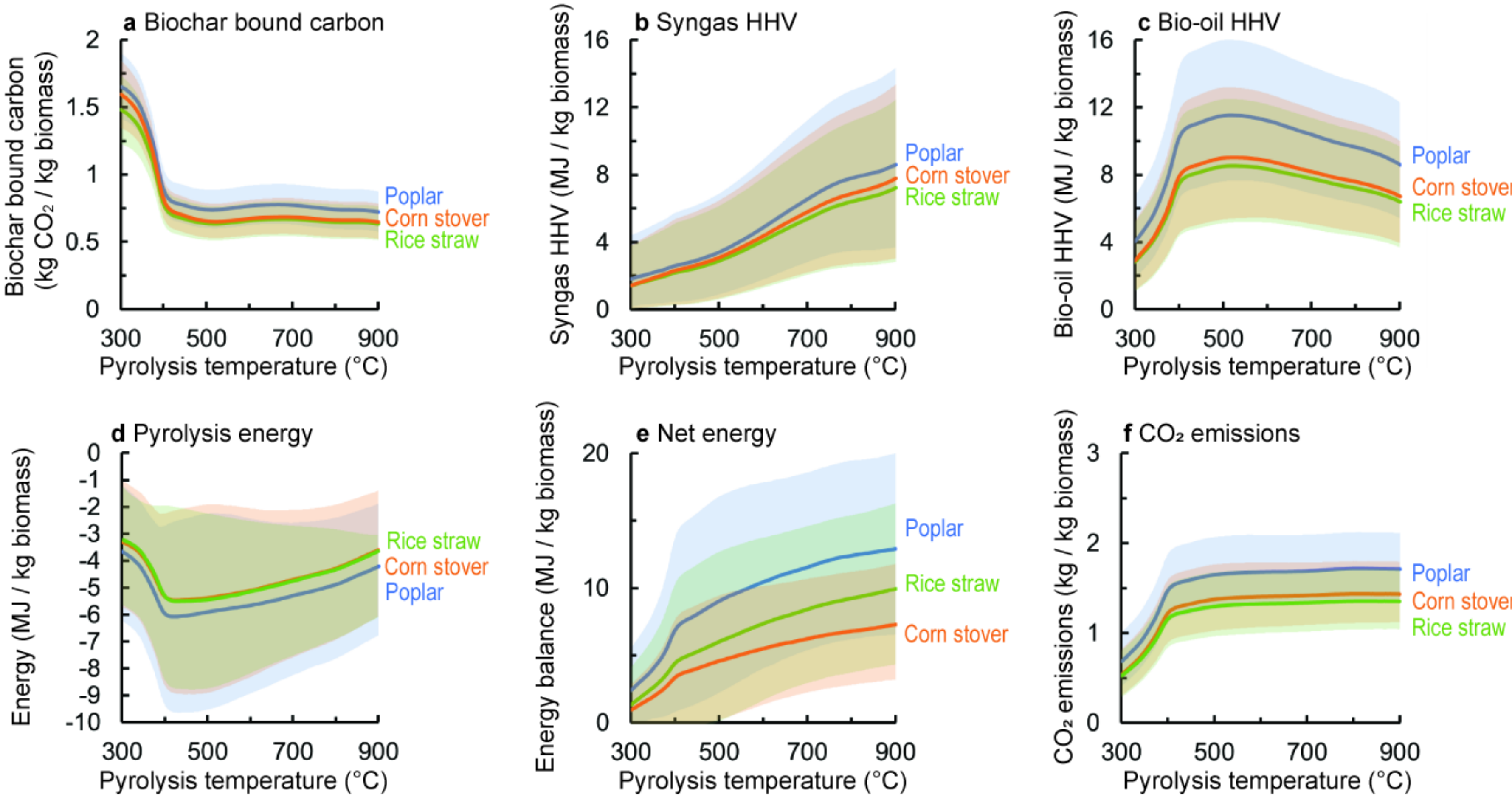

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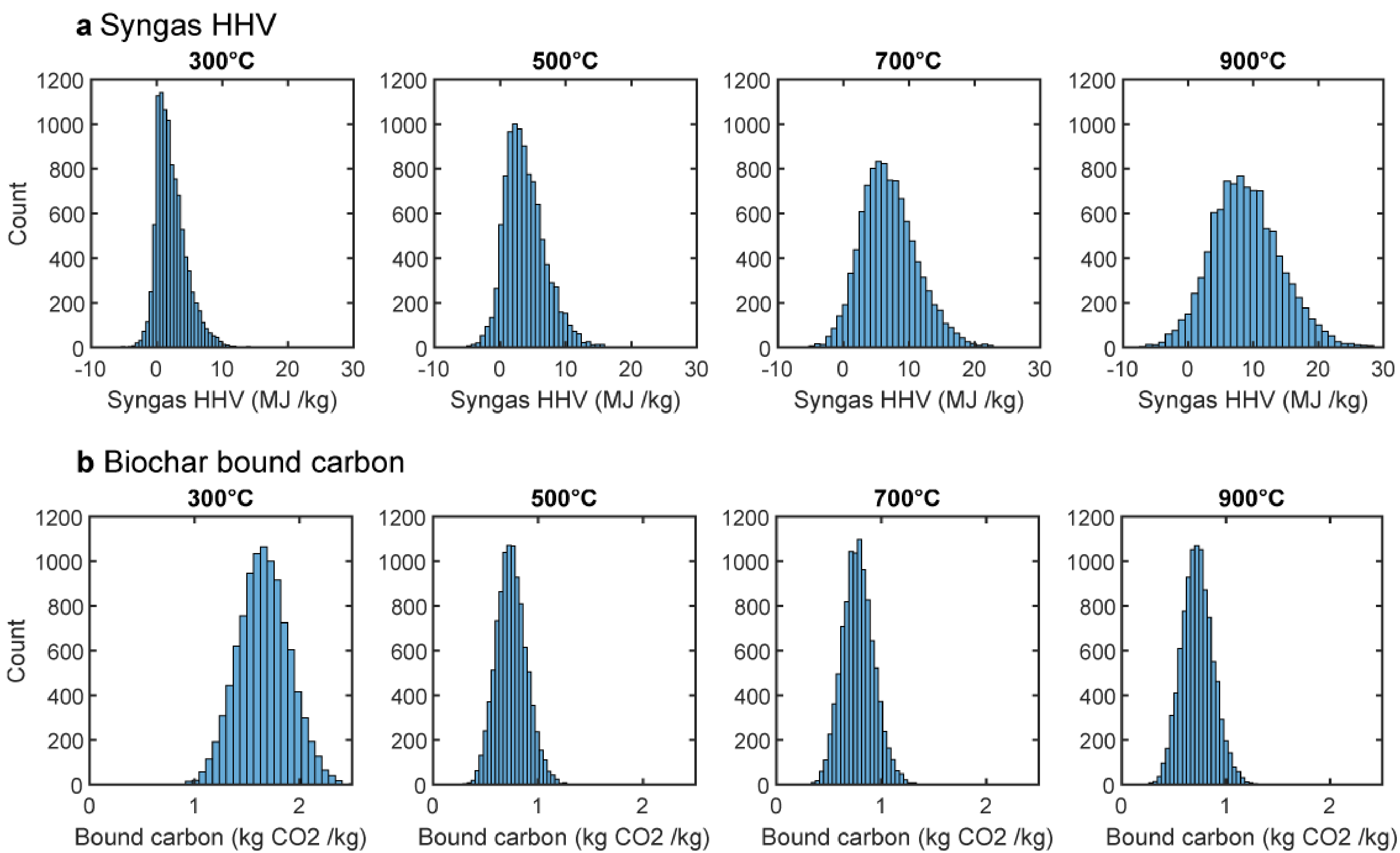

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