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Application of Machine Learning Techniques to Fast Pyrolysis Yields and Heating Value of Liquid Product

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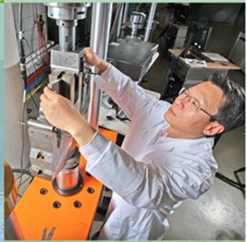


Canada

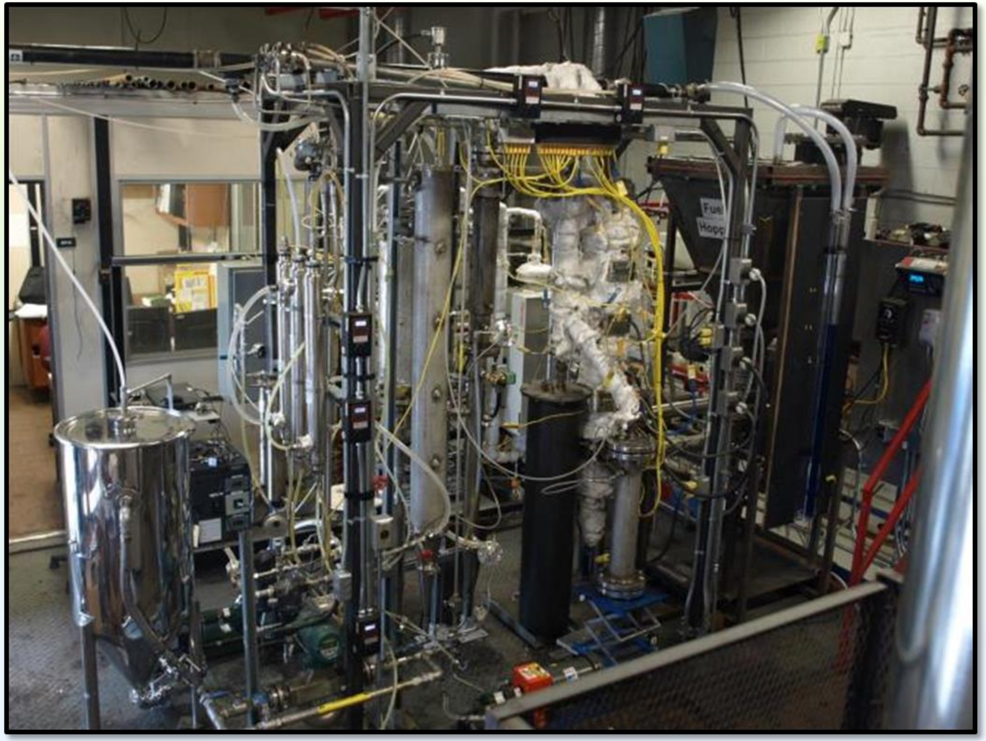
CanmetENERGY-Ottawa

CanmetENERGY Ottawa leads the development of energy S&T solutions for the environmental and economic benefit of Canadians.

Bioenergy Program

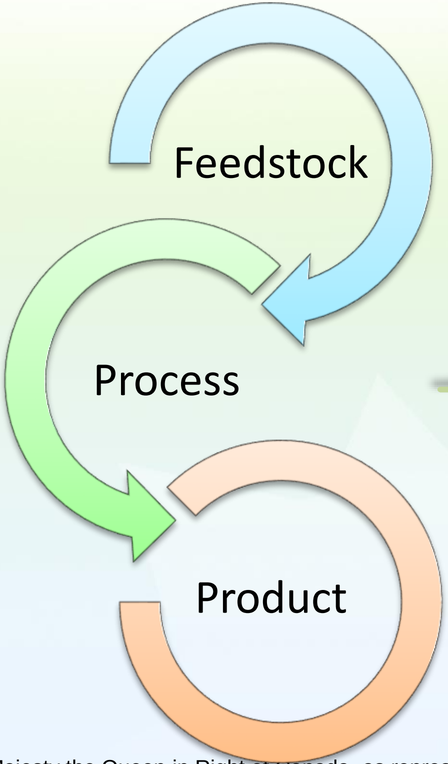
Increased utilization of biomass will allow Canadian industries to lower their carbon footprint while using secure, local, sustainable resources. Communities also derive economic and employment benefits from increased use of local resources. CE-O advances these national interests through innovation on conversion of biomass for energy and production of solid, liquid, and gaseous fuels.


Fast Pyrolysis Pilot Plant



- 5-10 kg/h bubbling fluidized bed
- Quench based condensation (immiscible hydrocarbon)
- Slipstream capabilities including catalytic vapour upgrading

Interactions of Feedstocks and Conversion Processes



Feedstock Characterization

-Forestry residues and products

-Agricultural residues and energy crops

-Waste, recycled or end-of-life materials

Thermochemical Conversion Performance and Yields (A few examples)

-Gasification

-Torrefaction & Carbonization

-Pyrolysis (fast, intermediate, slow)

-Hydrothermal carbonization

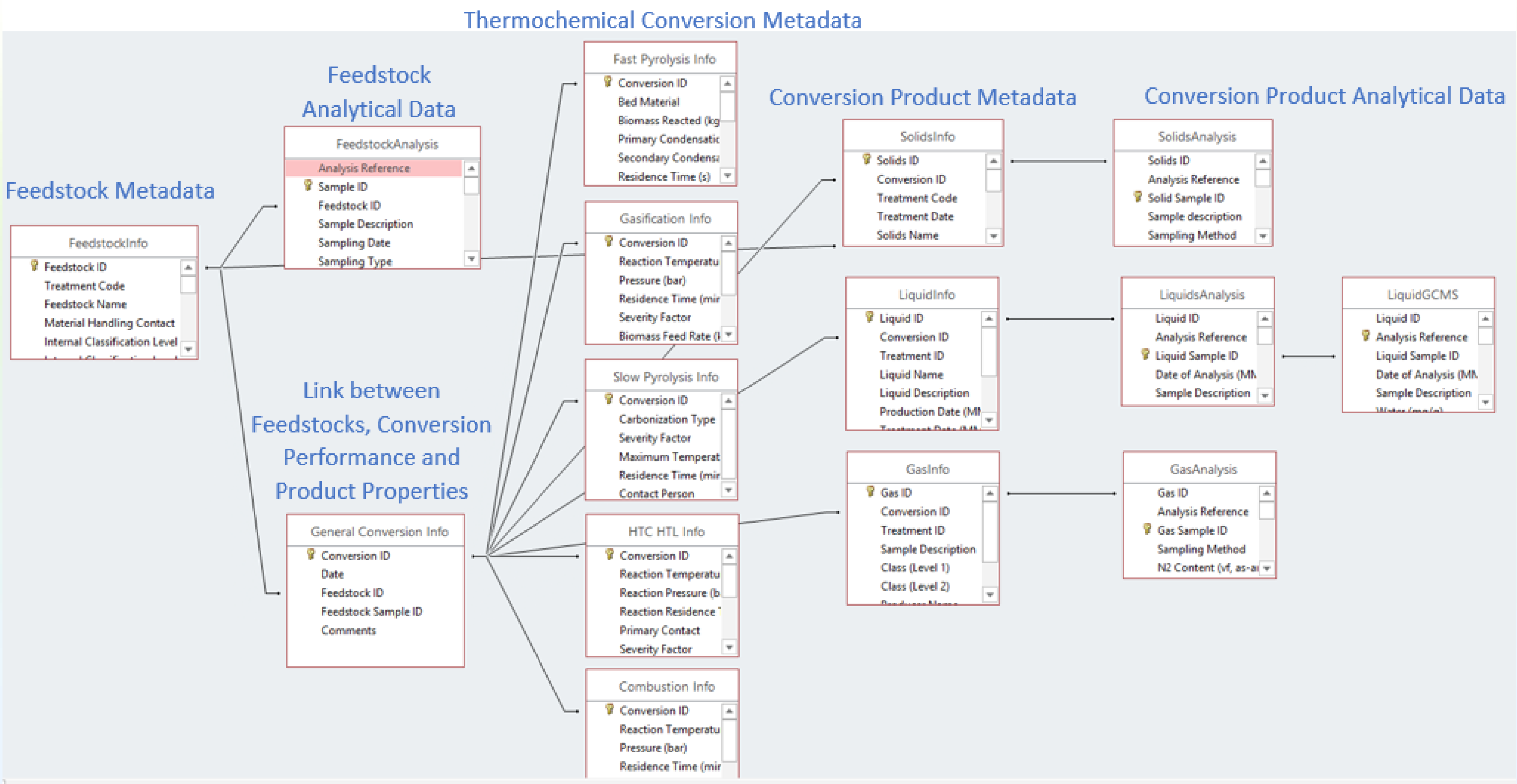
Conversion Product Characterization

-Intermediate or Product Gases streams

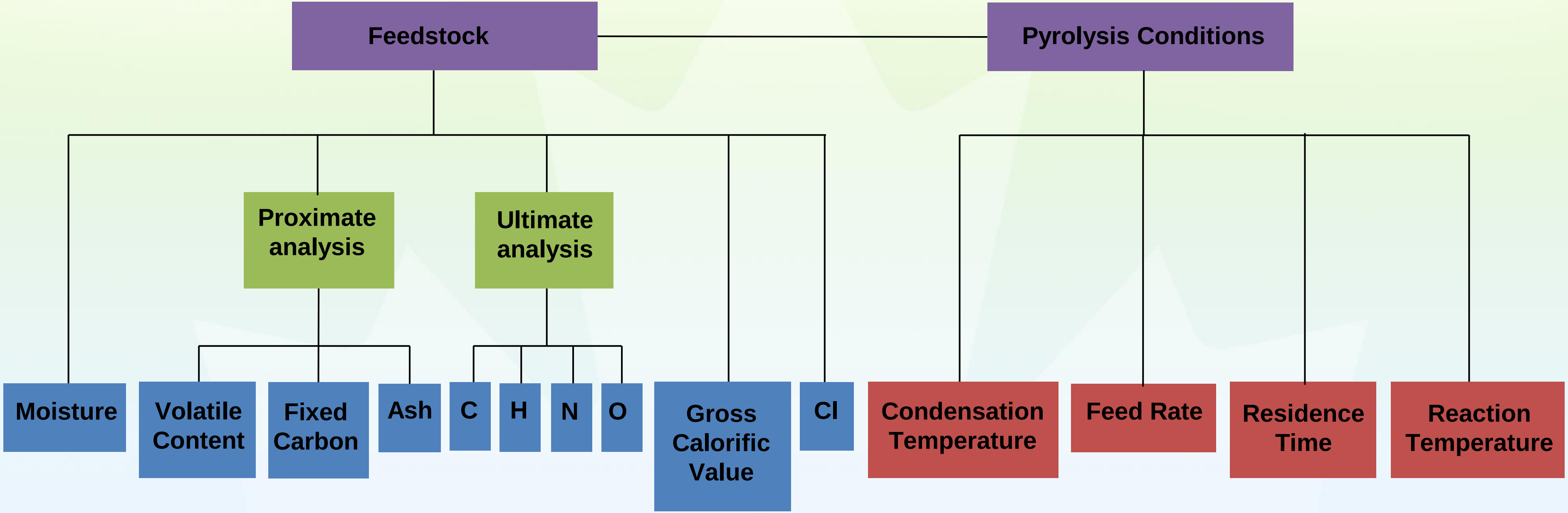
-Advanced Liquid streams (tars, aqueous condensates, bio-oils, biocrudes, etc.)

-Advanced solids streams (char, ash, etc.)

Database Layout

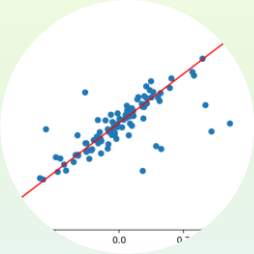


Data Set: Independent Variables



Machine Learning

Recognize patterns in data and generate complex models without programming instruction



MLR

Multilinear regression: find linear relationships by fitting covariables

GPR

Gaussian process regression: non parametric, Bayesian

RF

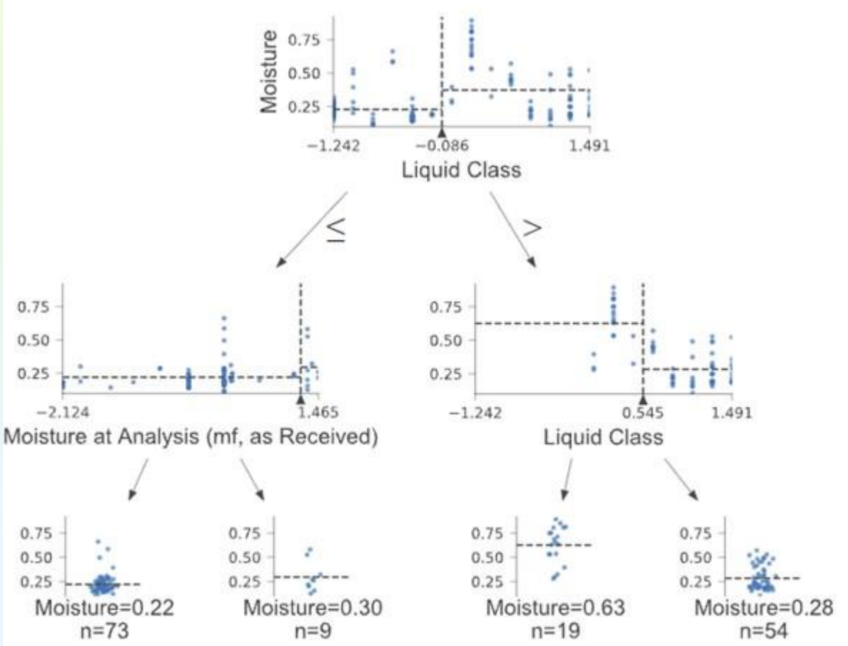
Random forest: averages the collection of decision trees

- **Train test split:** proportion of train test points
- **Random state:** determines how points are distributed

All modelling done with Python Scikit-learn.

Random Forests

Collection of n decision trees with depth d selected to minimize MSE.



Example of a tree from random forest with maximum depth of 2

Liquid Yield

Random Forest Model

98 points

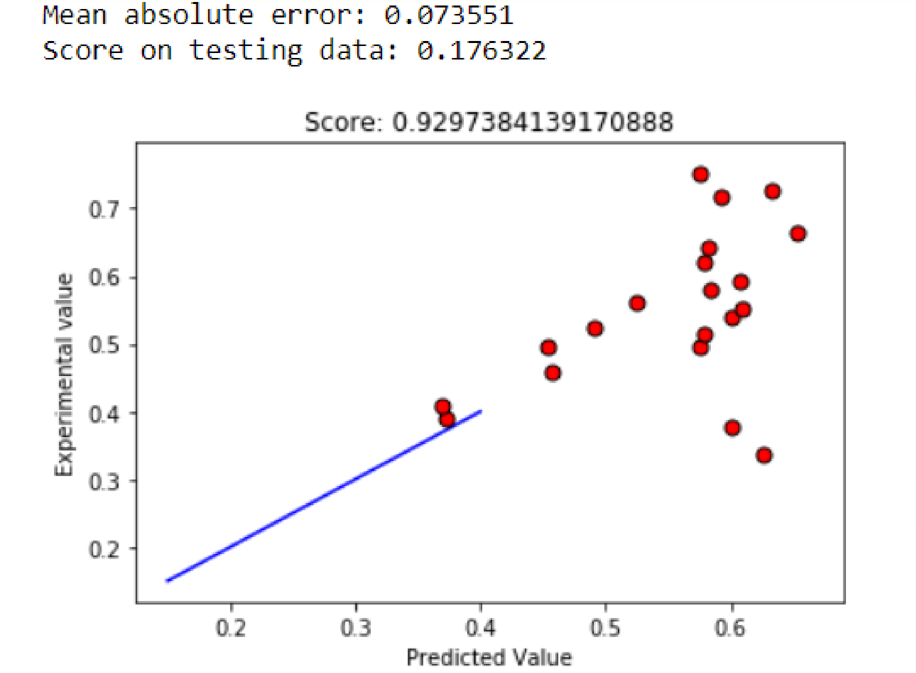
ash, volatile content, fixed C, C, H, N, O, HHV, gas residence time, FeedRate, Reactor Temperature

Training

0.912

Testing

0.344



Gas Yield

Random Forest Model

98 points

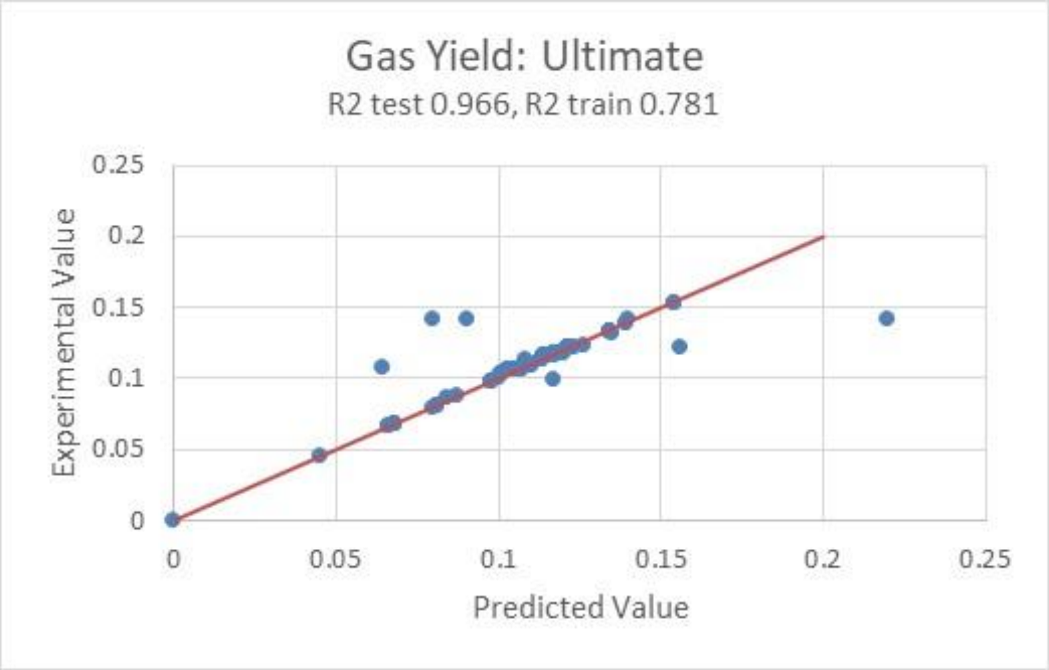
ash, volatile content, fixed C, C, H, N, O, HHV, gas residence time, FeedRate, Reactor Temperature

Training

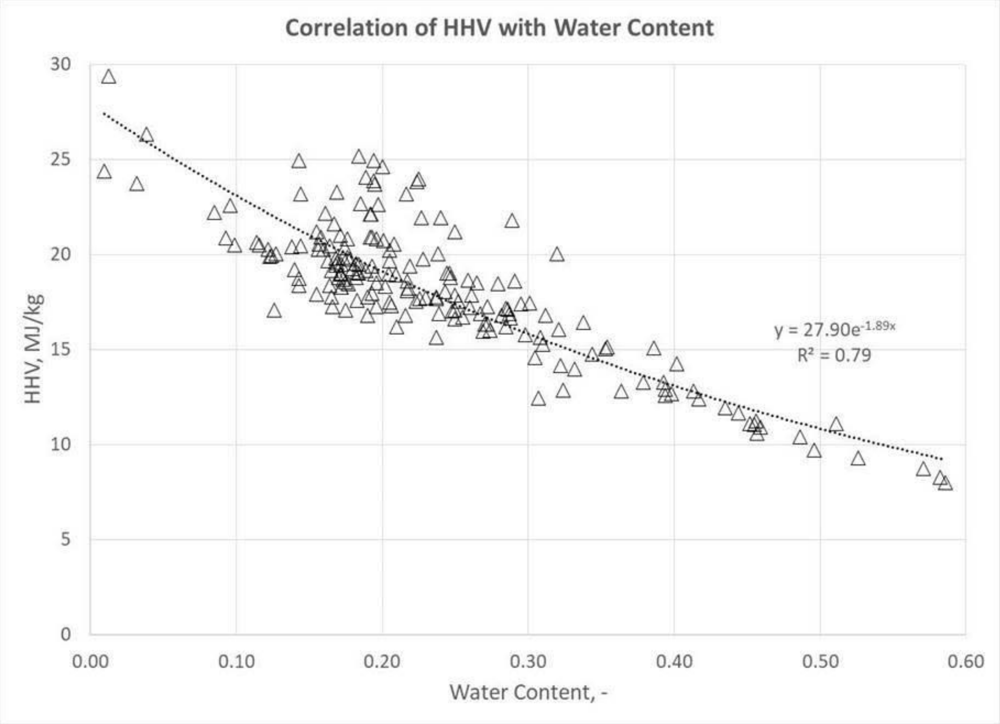
0.966

Testing

0.781



Heating Value



HHV is correlated with water content

Data conditioning

1 **Remove points**

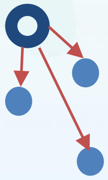
Aerosols, loblolly wood, VAPBIO, FB88M3D, RD 16, FB89F-L01, RD 16, RD 21, RD 22, ARI Oil Centrifuged

2 **Review assigned condensation temperatures**

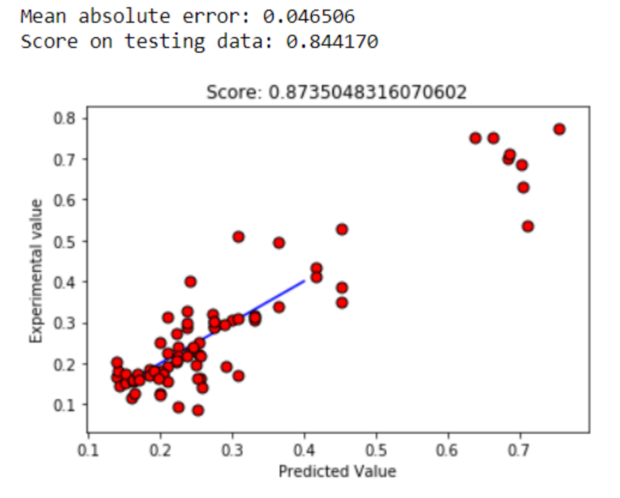
- **Run reports**
  - Primary condensate → higher
  - Secondary condensate → lower
- **Values entered in database**
- **Assign temperature**
  - Higher temperature 80 (9 points)
  - Lower temperature 10 → 30 (23 points)

3 **Imputation**

kNN selects the nearest neighbouring points and averages those values to fill in an empty data point



Water Content



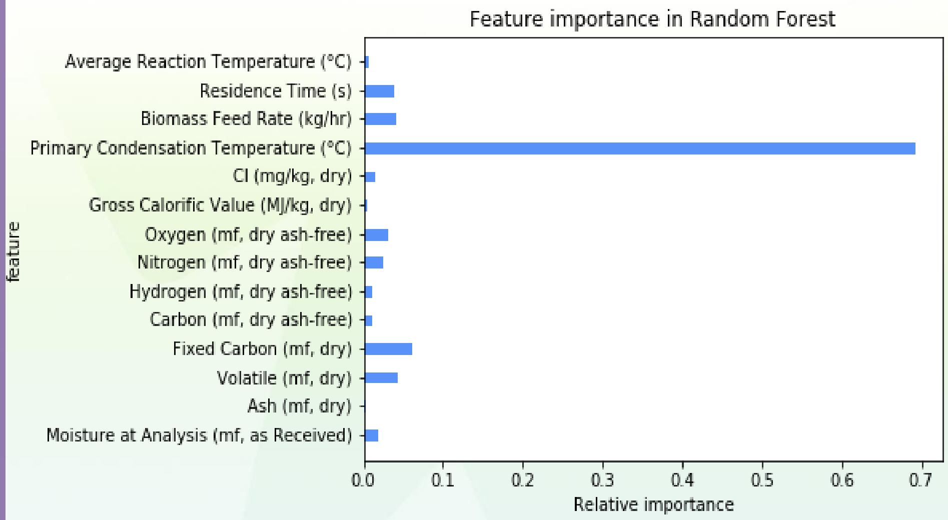
Training

0.853

Testing

0.769

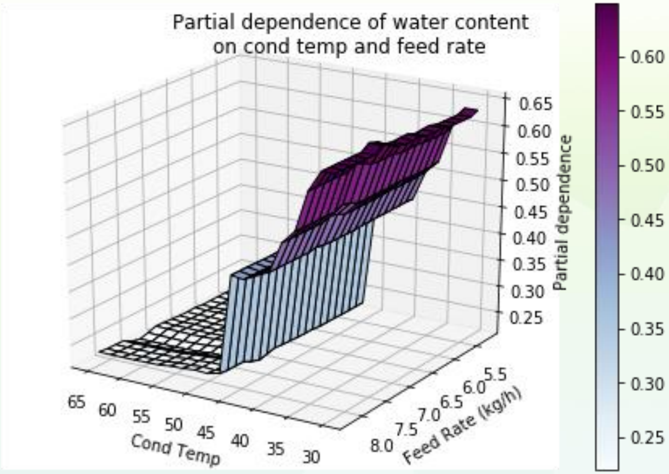
RF, 389 points, RS = 14, n estimators = 100, max depth = 5



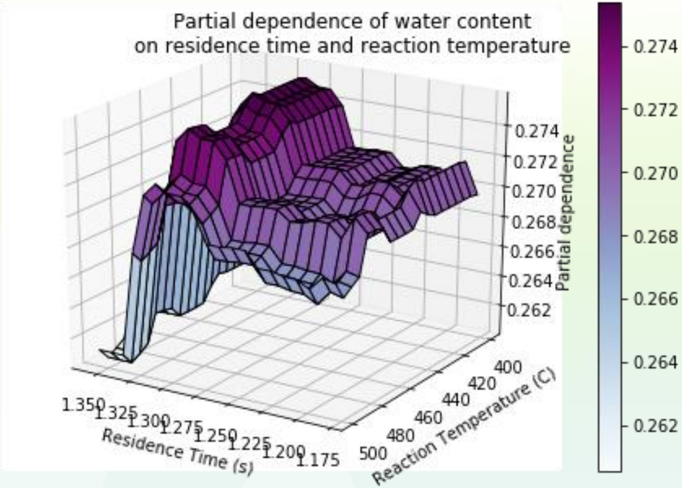
CE-O Model

Condensation temperature (0.64), volatile content (0.07), biomass feed rate (0.05), fixed carbon (0.04)

Influence of operating conditions



Vary water content based on condensation temperature and feed rate



Vary water content based on residence time and reaction temperature

Optimal conditions for low water content

Condensation temperature: 65 °C

Residence time: 1.4-1.8 s

Reaction temperature: 470-480 ° C

Liquid Yield – Literature Model*

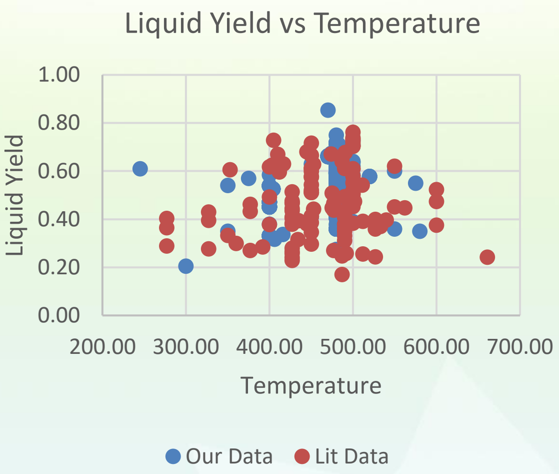
Leng et al. [2021]

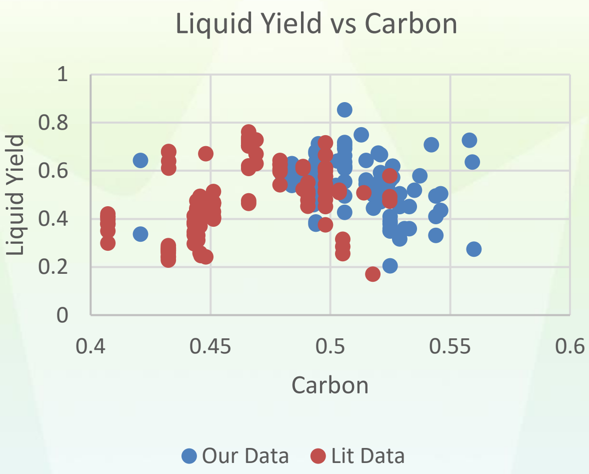
- Dataset collected from 29 literature sources from 1995 to 2019.
- Fast pyrolysis in bubbling fluid bed reactor.
- ML techniques applied to yields and HHV of liquid product.
- Model for liquid yield used 92 points
  - ash, VM, FC, C, H, N, O, feed rate, gas flow rate, reactor temperature, and particle size
- RF model with training R^2 = 0.950 and testing R^2 = 0.639 on literature dataset.
- Running that model on CE O dataset was unsuccessful (negative R^2 on testing).

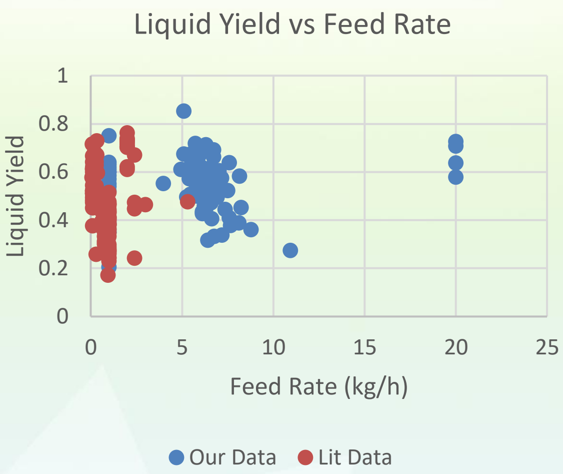
* Leng E, He B, Chen J, Liao G, Ma Y, Zhang F, Liu S, E J. (2021). Production of three-phase product distribution and bio-oil heating value of biomass fast pyrolysis based on machine learning. *Energy*. *236*: 121401

Liquid Yield

Exploring the discrepancy of models







Temperatures range from about 200-600 °C.

Literature data has lower carbon content (0.4-0.5) than our data (0.47-0.57).

Our data has higher feed rates than literature data (0.072-5.3).

Conclusion

- CE O fast pyrolysis dataset used to test ML algorithms for yield of liquid and gas, and HHV/water content of liquid product
- Moderate success for water content and gas yield; less successful on liquid yield.
- Comparison with literature model and dataset indicates need for proper scaling of data.

Thank you!

Any questions?

Picture of CE O pyrolysis liquid under magnification