Removal of PFAS Precursor Compounds Using GAC

CalgonCarbon
A Kuraray Company

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RESEARCH GOALS

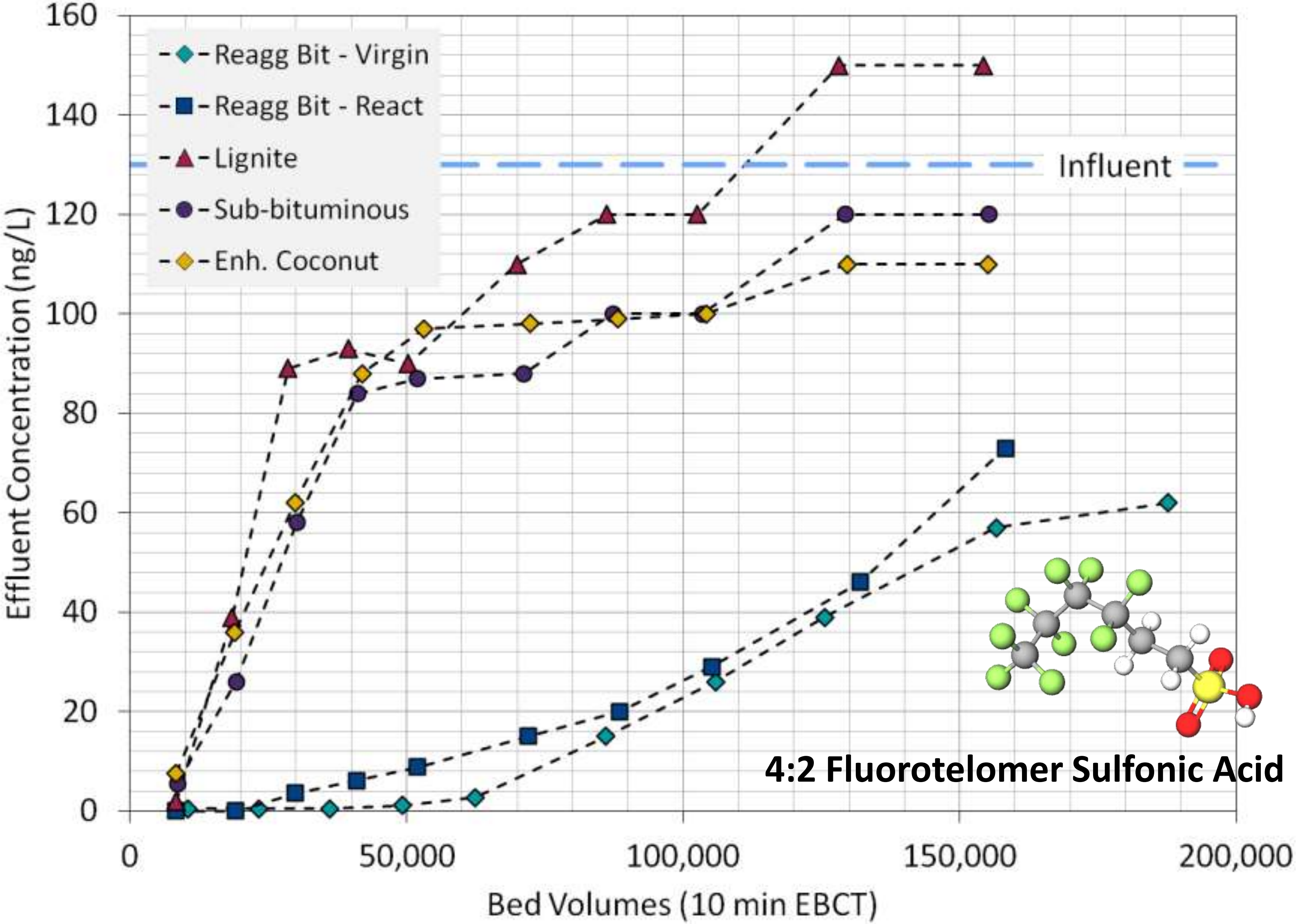
DEVELOP DATA SET FOR PFAS PRECURSOR REMOVAL

- RSSCTs – well-established method, relatively quick to run
- Target compounds: 4 fluorotelomers & 1 sulfonamide
- Compare multiple carbon types (5)
- PFOA & PFOS included in “background”

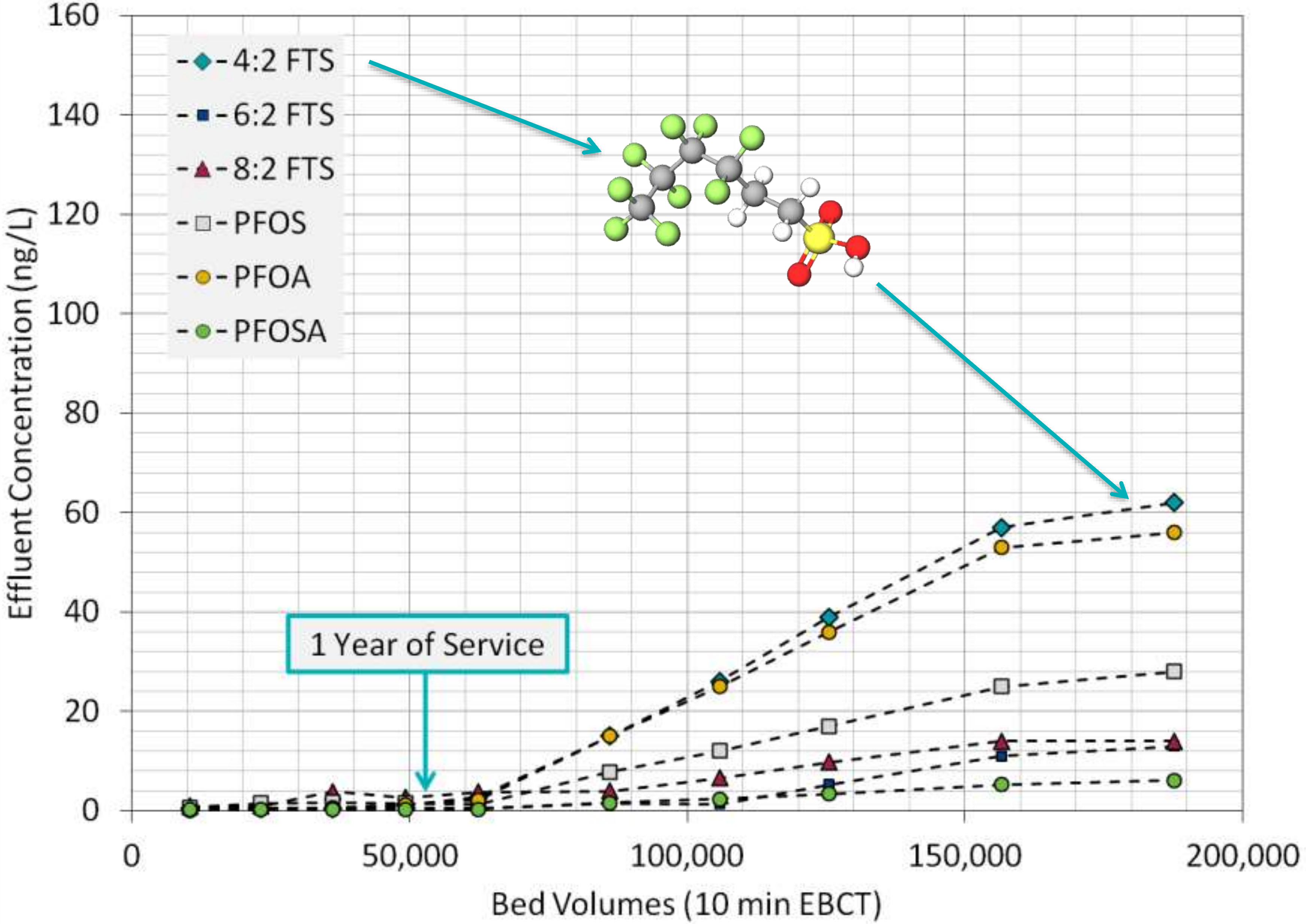
BETTER UNDERSTAND ROLE OF CARBON PROPERTIES

- Can pore volume distribution explain results?
- Can more “simple” test methods correlate to results?

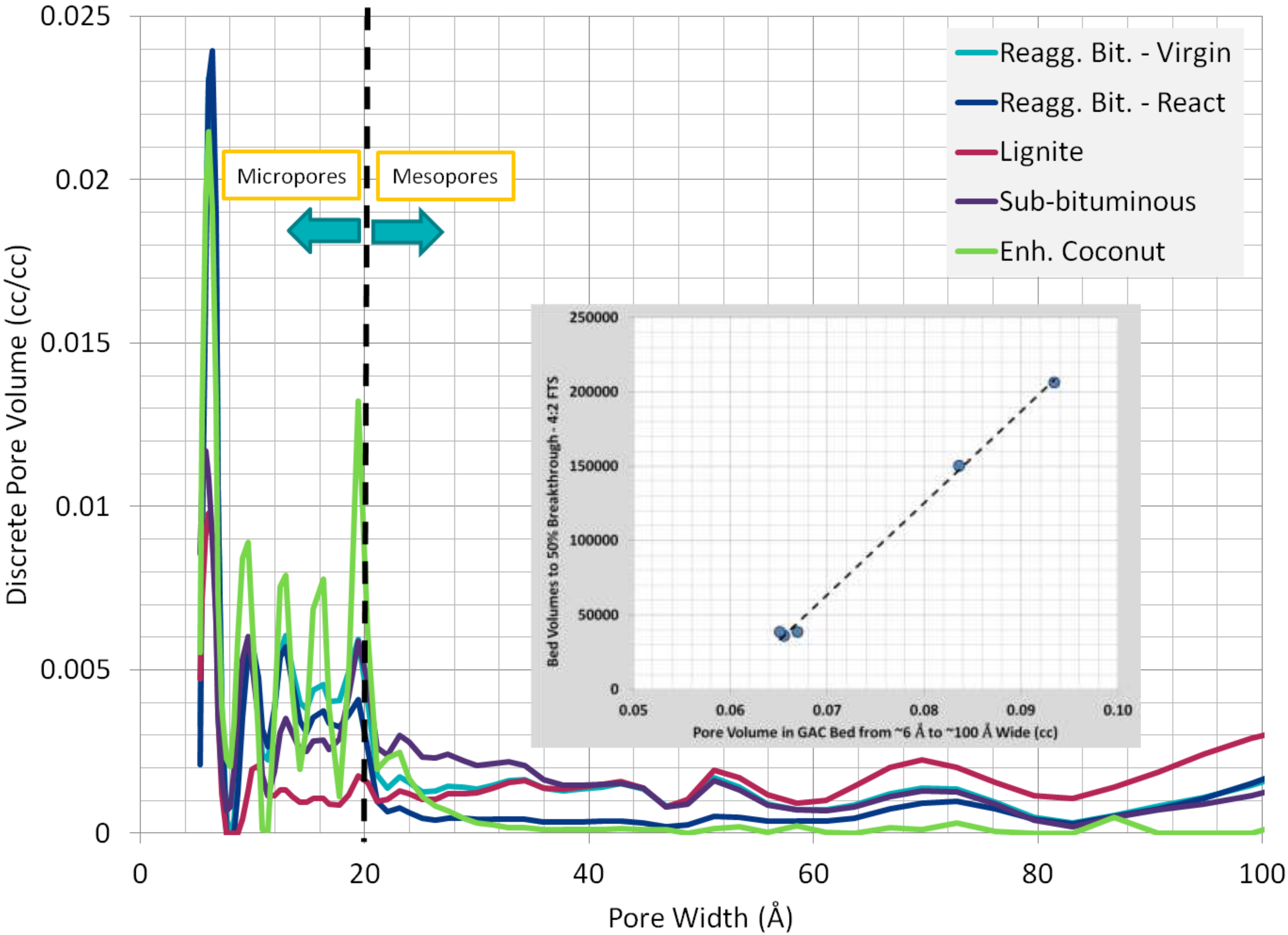
PREVIEW – RESULTS - 1



PREVIEW – RESULTS - 2



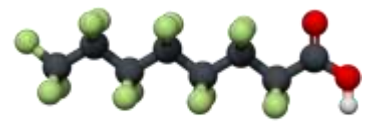
PREVIEW – RESULTS - 3



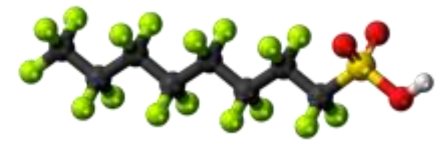
PFAS OVERVIEW

WHAT ARE PFAS?

- Poly- and perfluoroalkyl substances
- Class of man-made fluorinated compounds



PFOA Molecule



PFOS Molecule

Health Advisory:
70 ppt
Combined
PFOA / PFOS

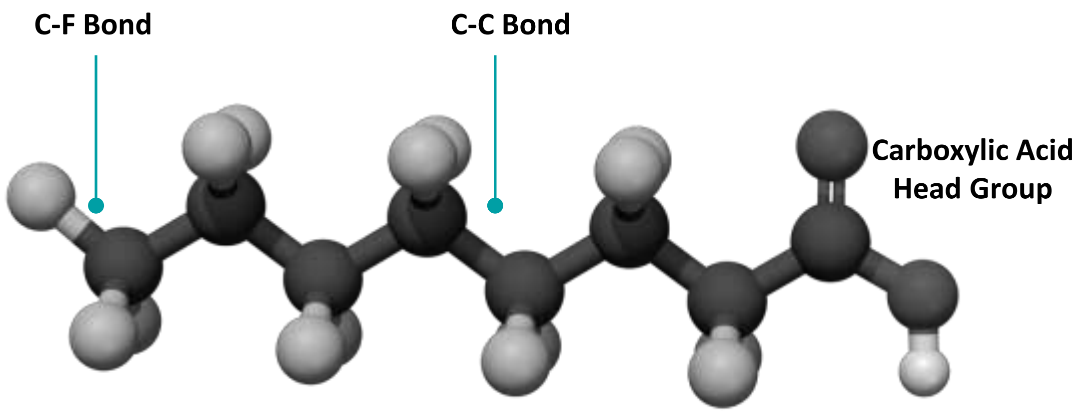
WHY ARE THEY A PROBLEM?

- Contaminates drinking water and food
- Highly persistent / resistant to degradation
- Accumulate in the body

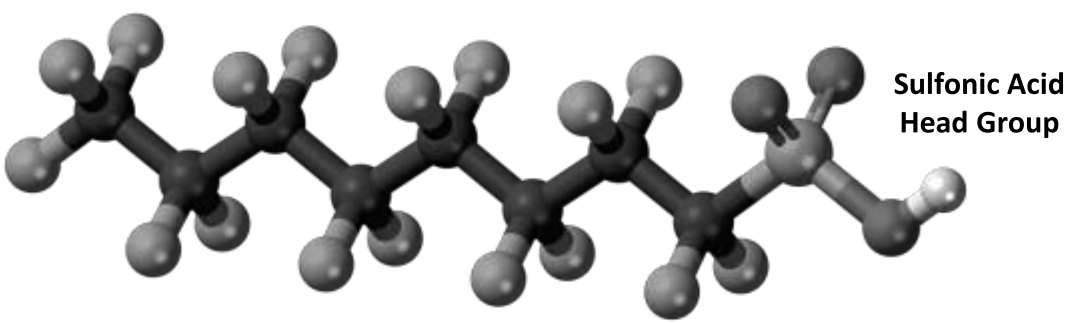
WHERE DO THEY COME FROM?

PFAS are used in a variety of products as a surface-active agent

PFAS Molecular Characteristics



PFOA MOLECULE



PFOS MOLECULE

CHEMICALLY STABLE

- Carbon Chain backbone
- C-F Bond

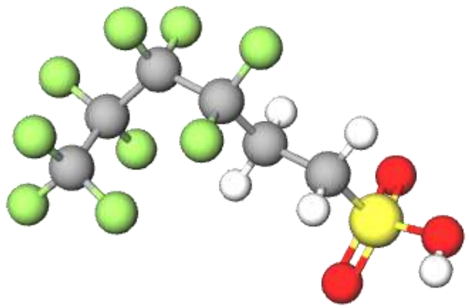
RELATIVELY HIGH MOLECULAR WEIGHT

LOW VAPOR PRESSURE

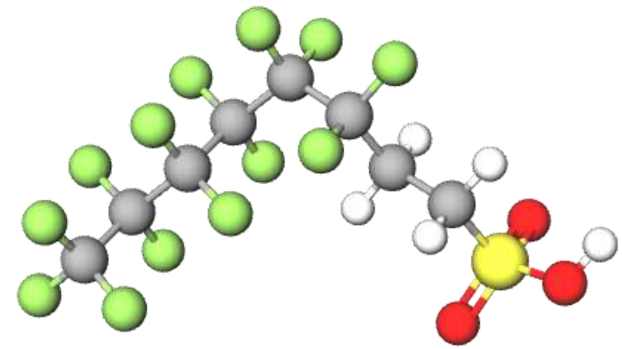
EASILY INFILTRATES INTO GROUNDWATER & SOIL

BIOACCUMULATES IN ORGANISMS

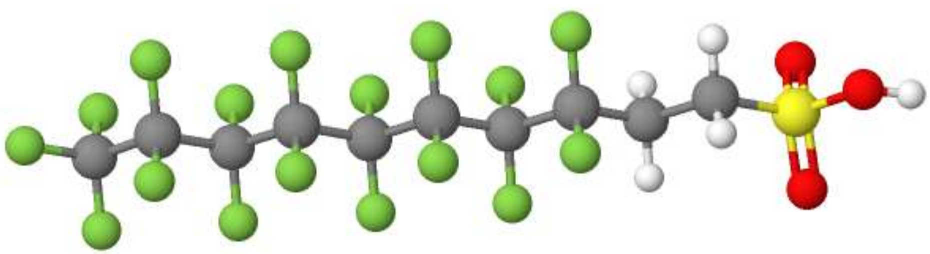
PFAS PRECURSORS



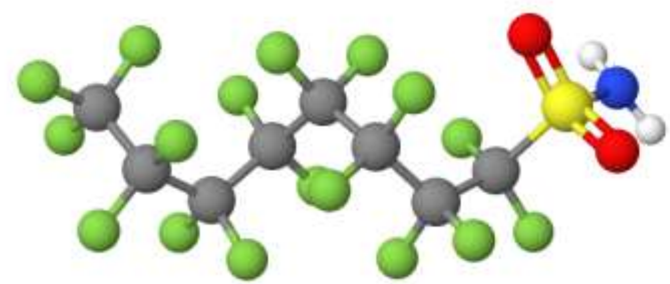
4:2 Fluorotelomer Sulfonic Acid
(4:2 FTS)



6:2 Fluorotelomer Sulfonic Acid
(6:2 FTS)

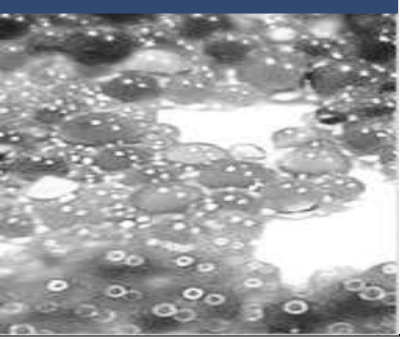


8:2 Fluorotelomer Sulfonic Acid
(8:2 FTS)



Perfluorooctane Sulfonamide

PFAS TREATMENT TECHNOLOGY

TREATMENT OPTION	PROS	CONS
	• Significantly lower capital costs • Significantly lower O&M costs • Reactivation saves cost, destroys PFASs, & removes liability • Established BAT for a long list of organic contaminants	• High Natural Organic Matter (NOM) can increase use rates • Removal efficacy varies by size/weight/solubility of contaminant
	• Removes salts / inorganics that GAC cannot	• Concentrated waste water disposal liabilities & costs • More energy / CO_2 intensive • High maintenance cleaning and replacement of fouled membranes • Removes healthy minerals
	• Resin can be regenerated • May be more economical at high concentrations of PFAS (generally much higher than drinking water applications – primarily remediation applications only)	• High cost of media • Regeneration produces disposal liabilities & costs • Regeneration requires both brine and a solvent (e.g. methanol)

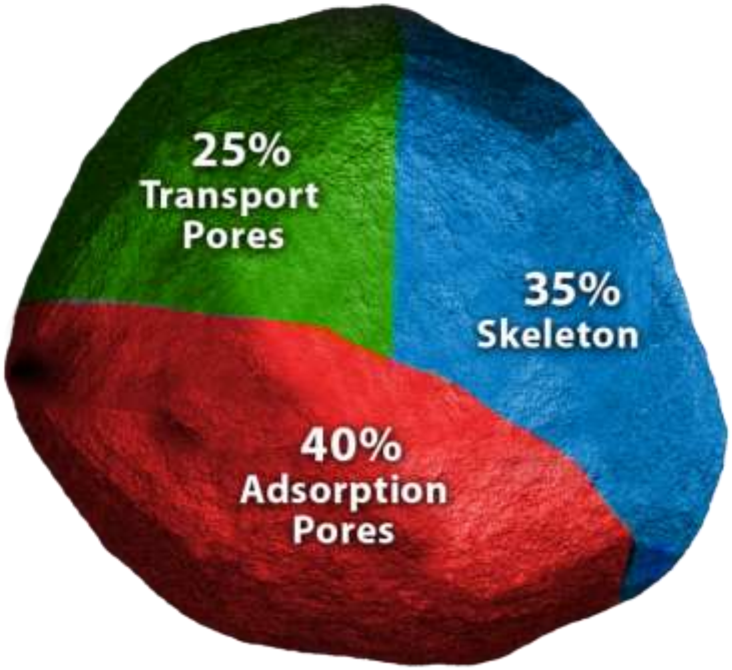
STRUCTURE OF ACTIVATED CARBON

Adsorption Pores

- Finest pores in structure
- Termed "<u>micro</u>pores"
- <20Å diameter

Transport Pores

- Diffusion pathways to transport adsorbates
- Termed "<u>meso</u>pores"
- 20Å - 500 Å diameter



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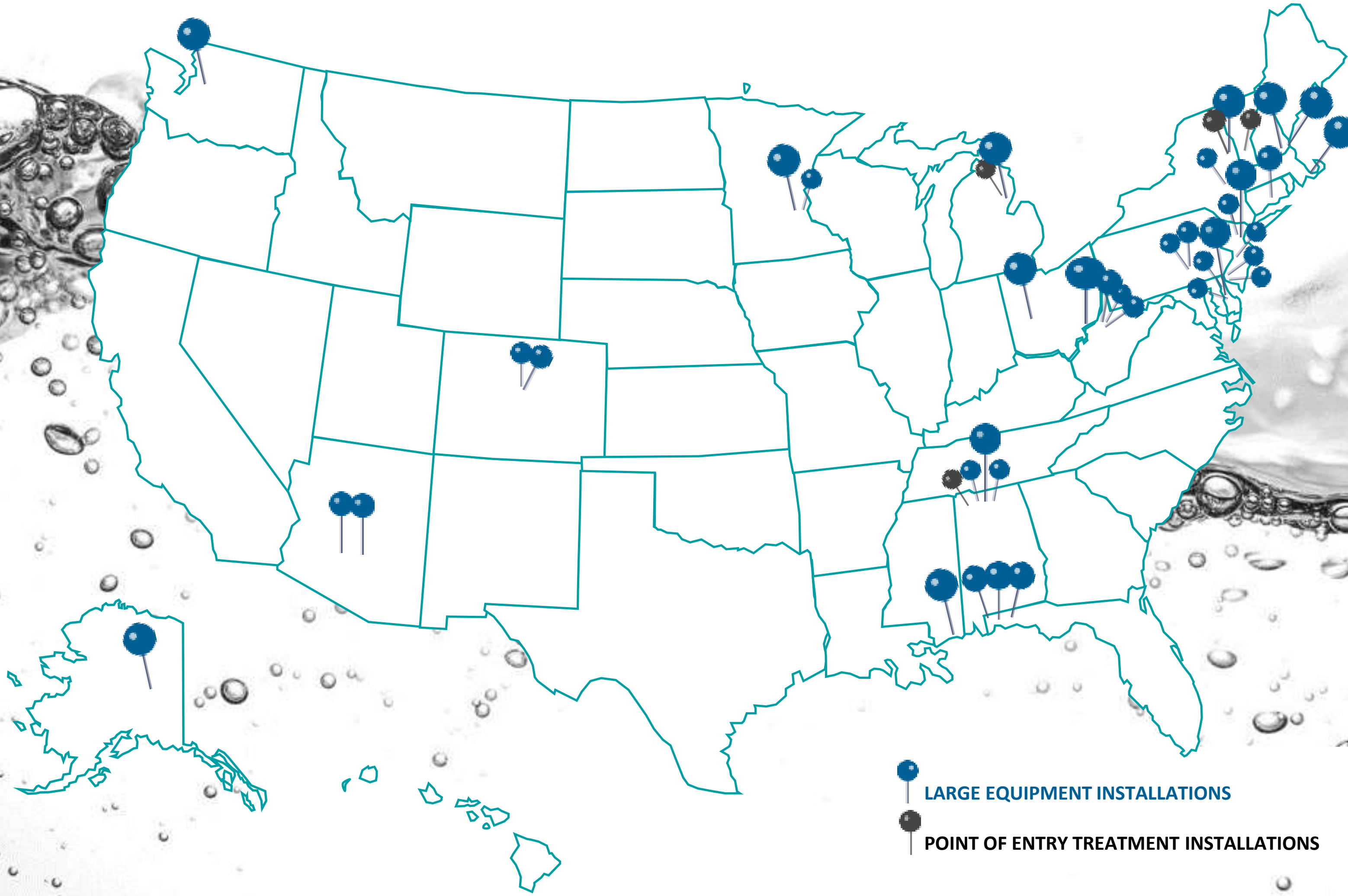
PFAS TREATMENT LOCATIONS



40+ INSTALLATIONS ACROSS THE US

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TREATMENT METHODOLOGY

DUAL VESSEL TREATMENT

- Maximize carbon loading
- Simplify carbon exchange logistics
- Redundancy

SUFFICIENT CONTACT TIME IS CRITICAL FOR EFFECTIVE REMOVAL

- Kinetics and Thermodynamics of adsorption must be considered
- 10 minutes EBCT per vessel minimum

REMOVAL STUDY
RSSCTs

Five GAC products evaluated under identical equivalent full-scale operating conditions and influent water quality

GAC DETAILS

GAC Source Material	Full-Scale Mesh Size	Apparent Density	Iodine Number (mg/g)	Xylenol Orange Dye Number (mg/g/hr)	Molasses Number
Reagglomerated Bituminous Coal - Virgin	12 × 40	0.543	1030	13.5	189
Reagglomerated Bituminous Coal – React.	12 × 40	0.546	905	13.4	236
Lignite Coal	12 × 40	0.377	605	17.4	416
Sub-Bituminous Coal	12 × 40	0.350	1015	21.7	154
Coconut Shell	12 × 30	0.414	1290	13.5	288

GAC COMPARISON
TEST CONDITIONS - 1

OPERATING PARAMETERS

- 10 minutes empty-bed contact time (EBCT).
- Pennsylvania groundwater spike with PFAS.

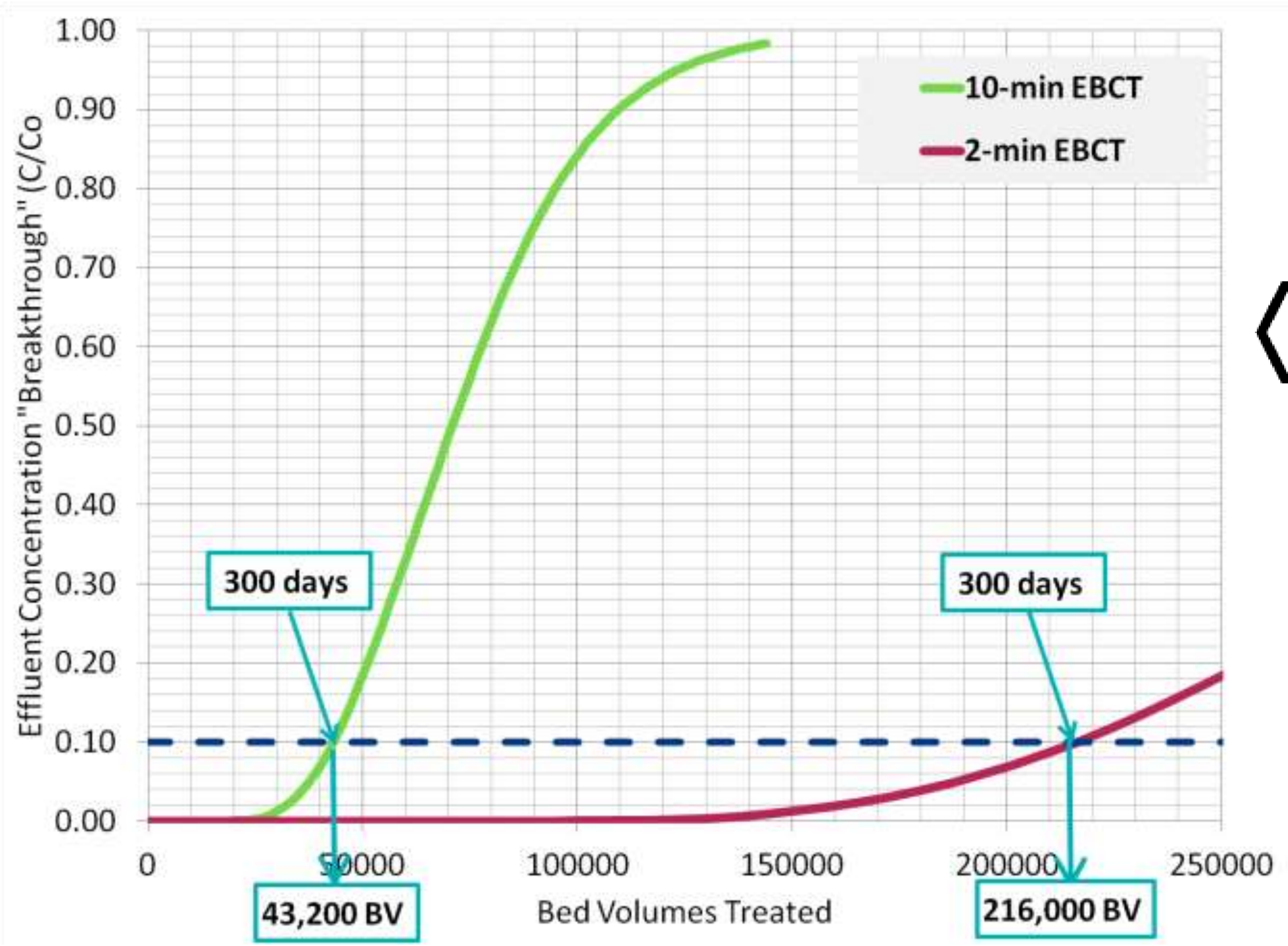
Compound	Abbreviation	Avg. Influent Concentration (ng/L)
4:2 Fluorotelomer Sulfonic Acid	4:2 FTS	130
6:2 Fluorotelomer Sulfonic Acid	6:2 FTS	43
8:2 Fluorotelomer Sulfonic Acid	8:2 FTS	56
Perflurooctanesulfonic Acid	PFOS	153
Perflurooctanoic Acid	PFOA	177
Perflurooctane Sulfonamide	PFOSA	39

GAC COMPARISON
TEST CONDITIONS - 2

WATER QUALITY

Component	Value	Units
pH	8.1	-
Total Dissolved Solids	670	mg/L
Alkalinity	105	mg/L as $CaCO_3$
Total Organic Carbon	0.3	mg/L

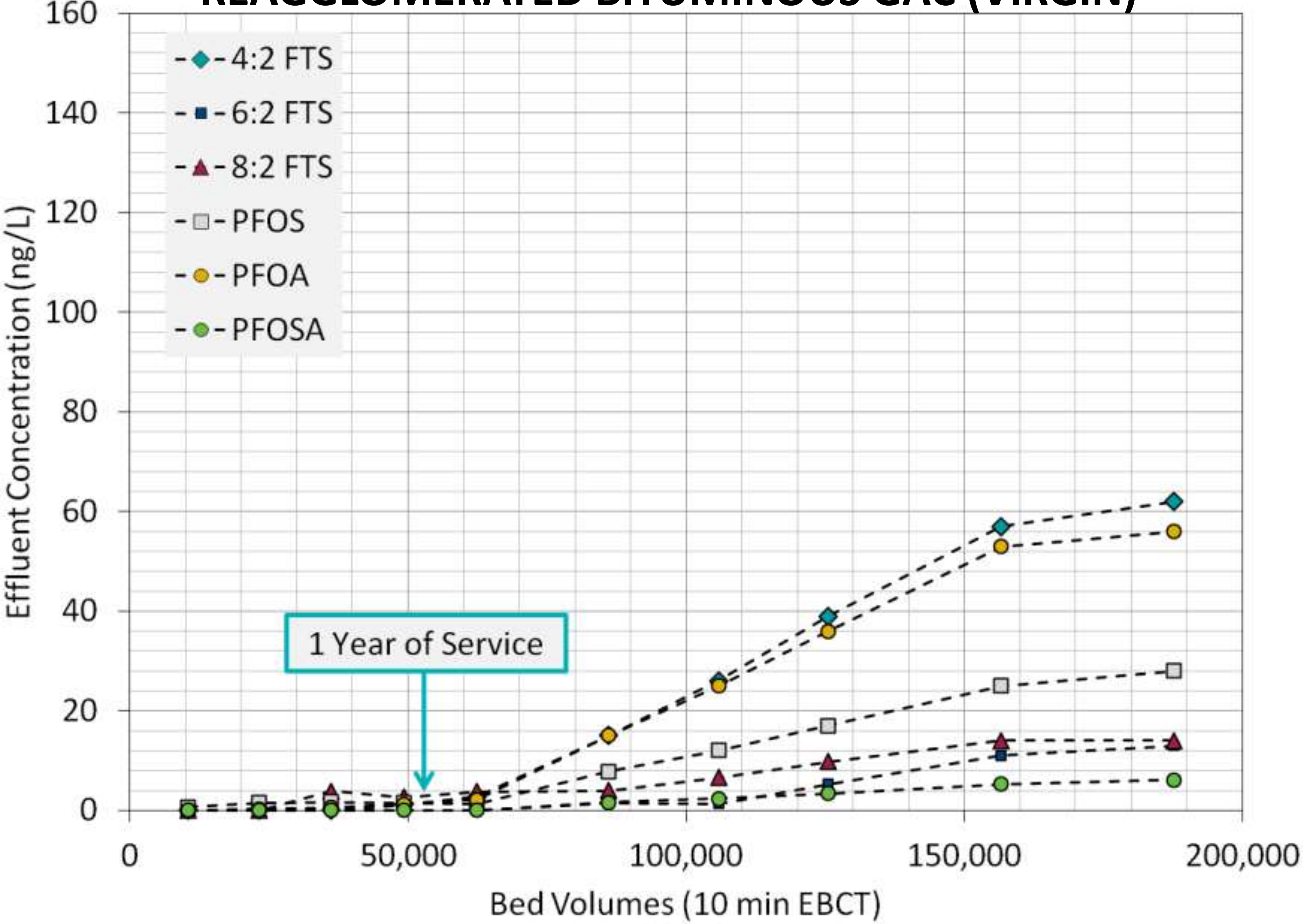
REFRESHER: READING BREAKTHROUGH CURVES



REMEMBER

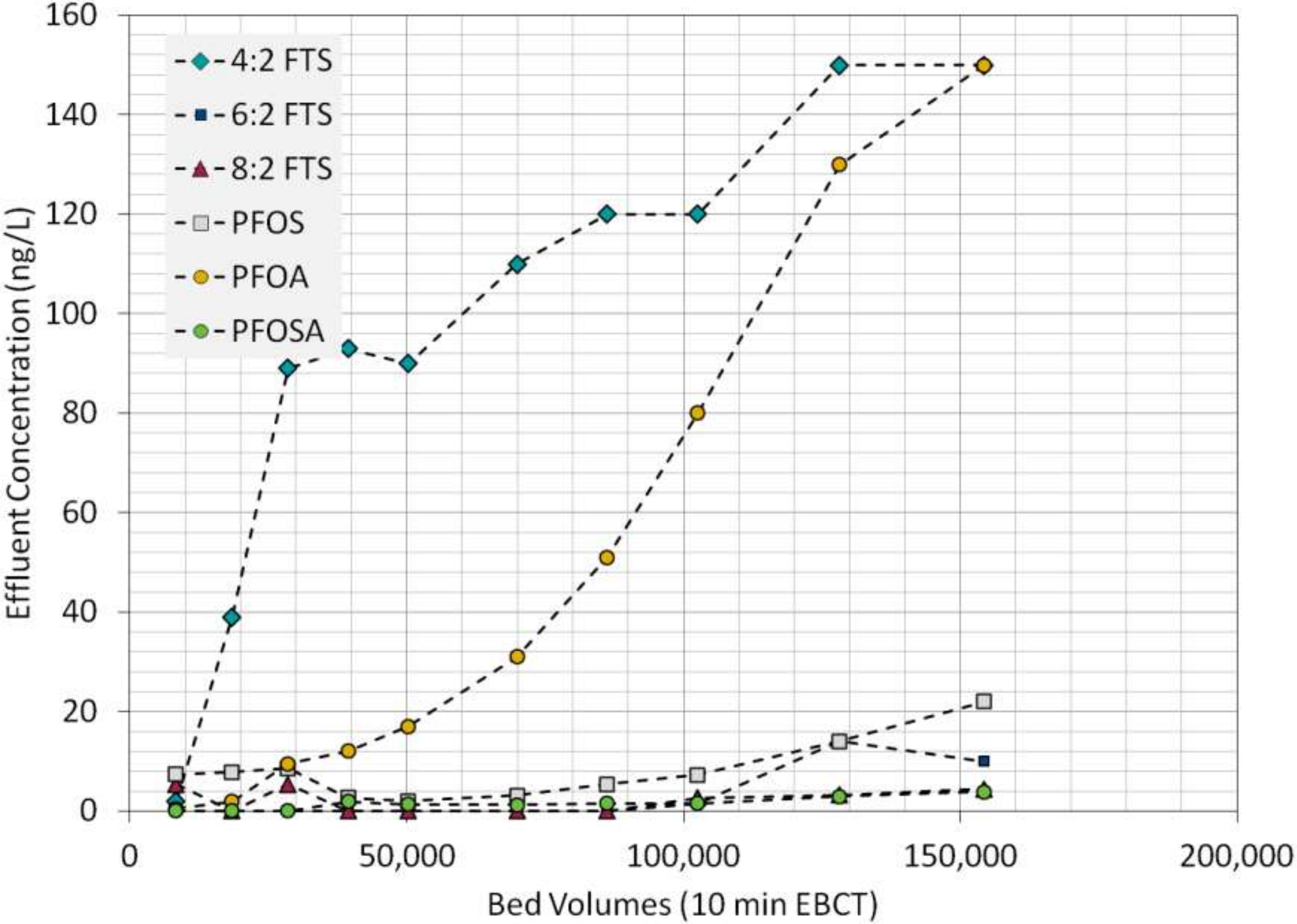
- Usually shown as normalized values.
- C/Co - What is influent concentration?
- “Bed Volumes” does not equal actual run time.

PFAS BREAKTHROUGH CURVES
REAGGLOMERATED BITUMINOUS GAC (VIRGIN)



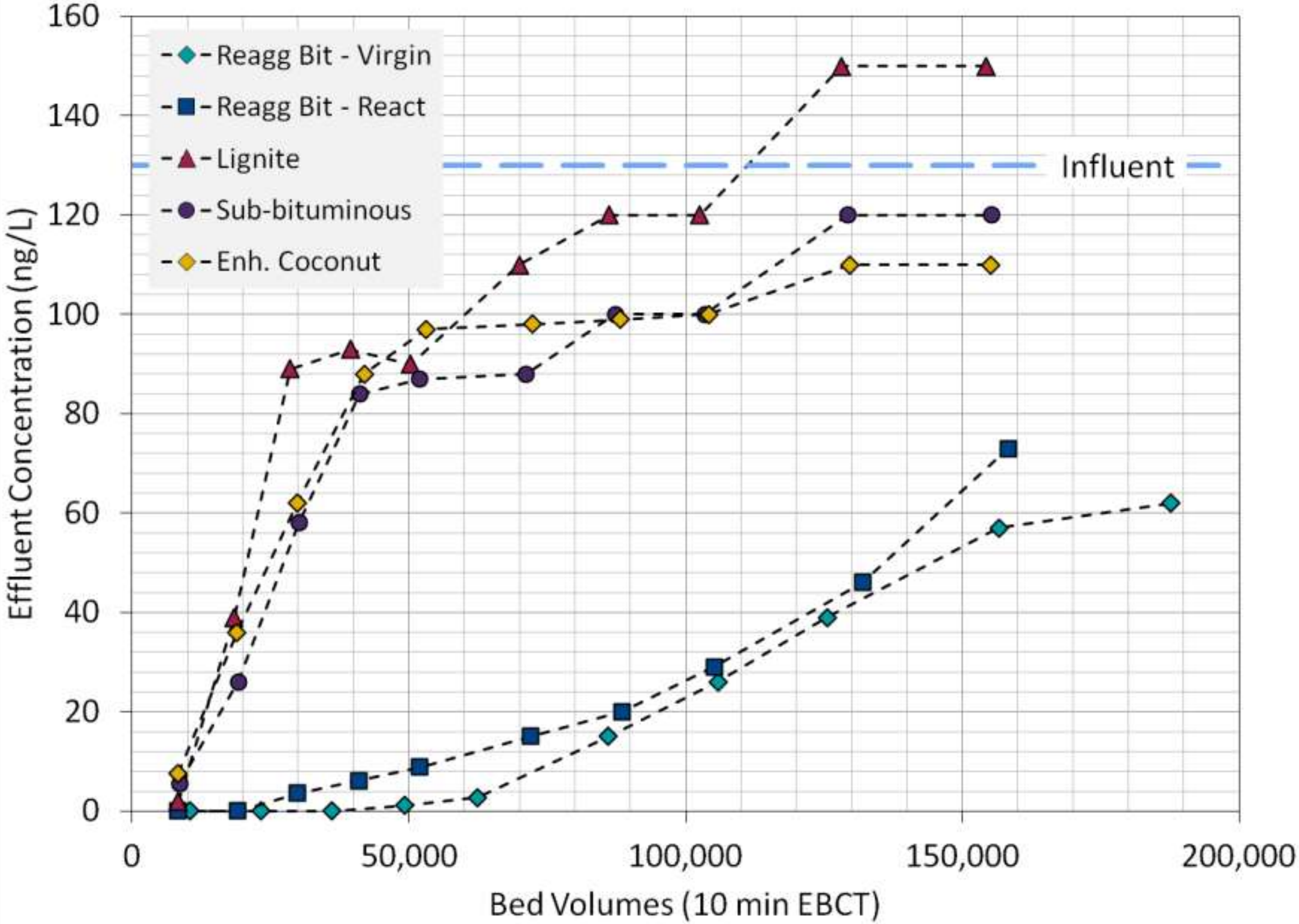
PFAS BREAKTHROUGH CURVES

LIGNITE-BASED GAC



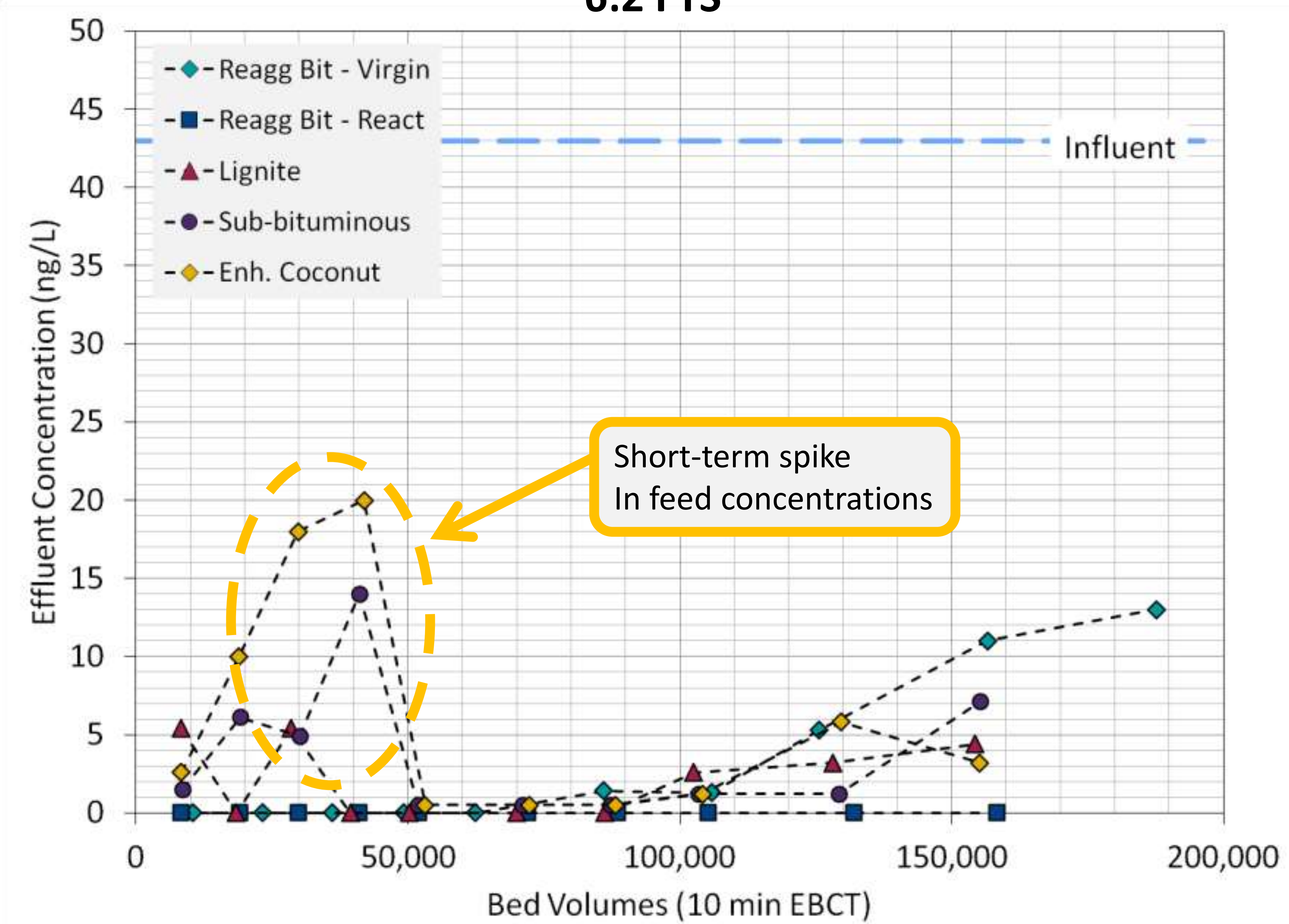
PFAS BREAKTHROUGH CURVES

4:2 FTS



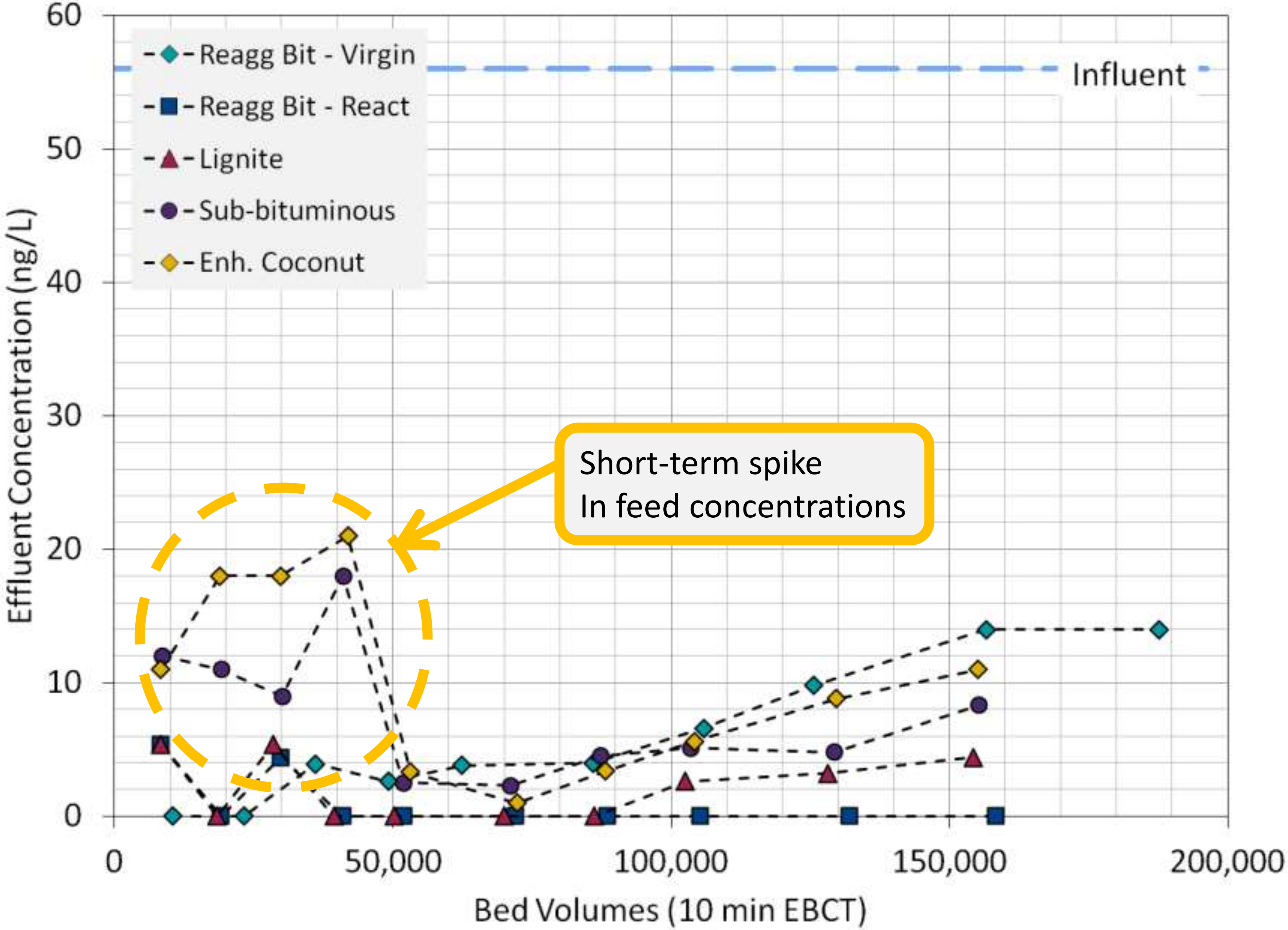
PFAS BREAKTHROUGH CURVES

6:2 FTS



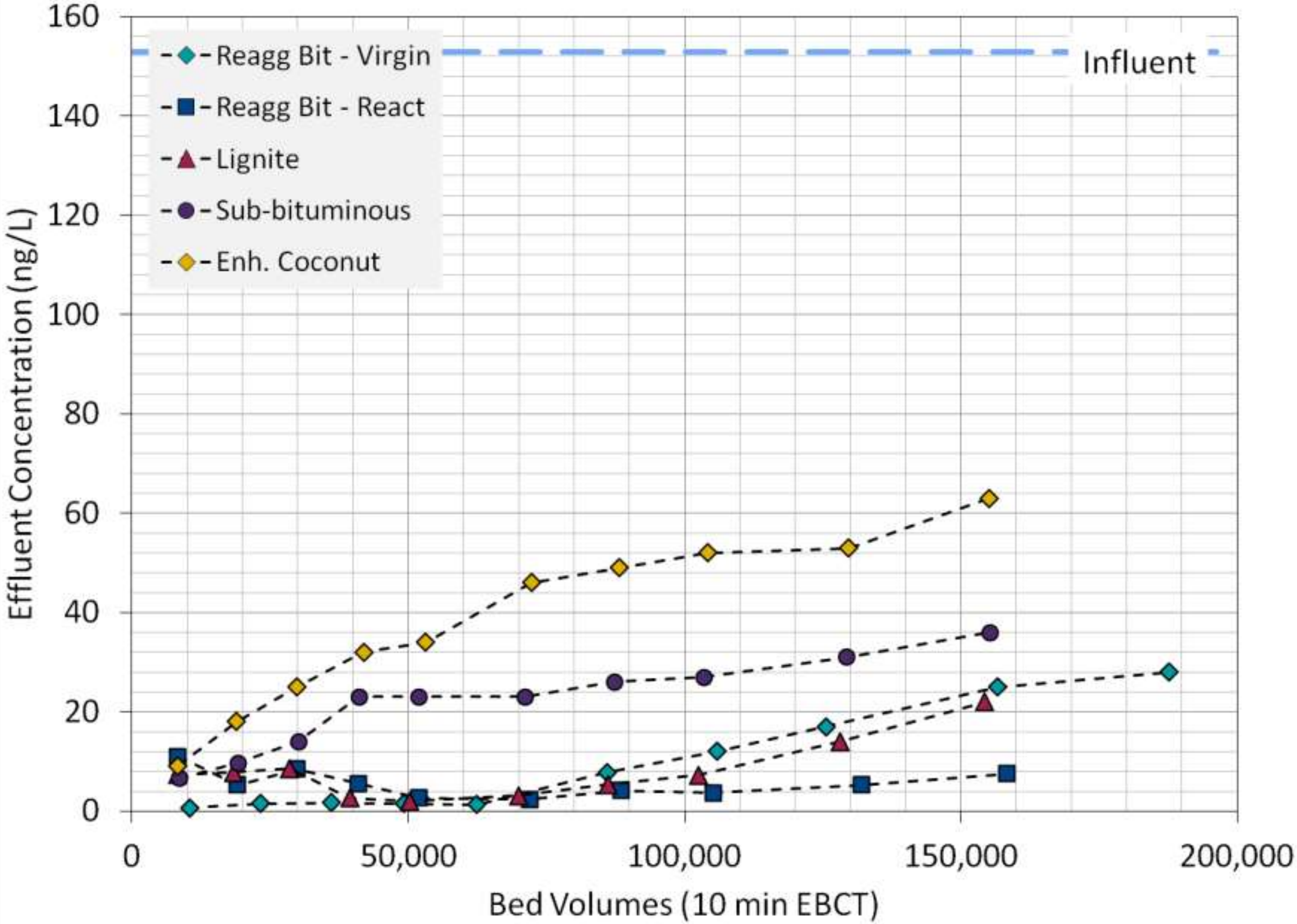
PFAS BREAKTHROUGH CURVES

8:2 FTS



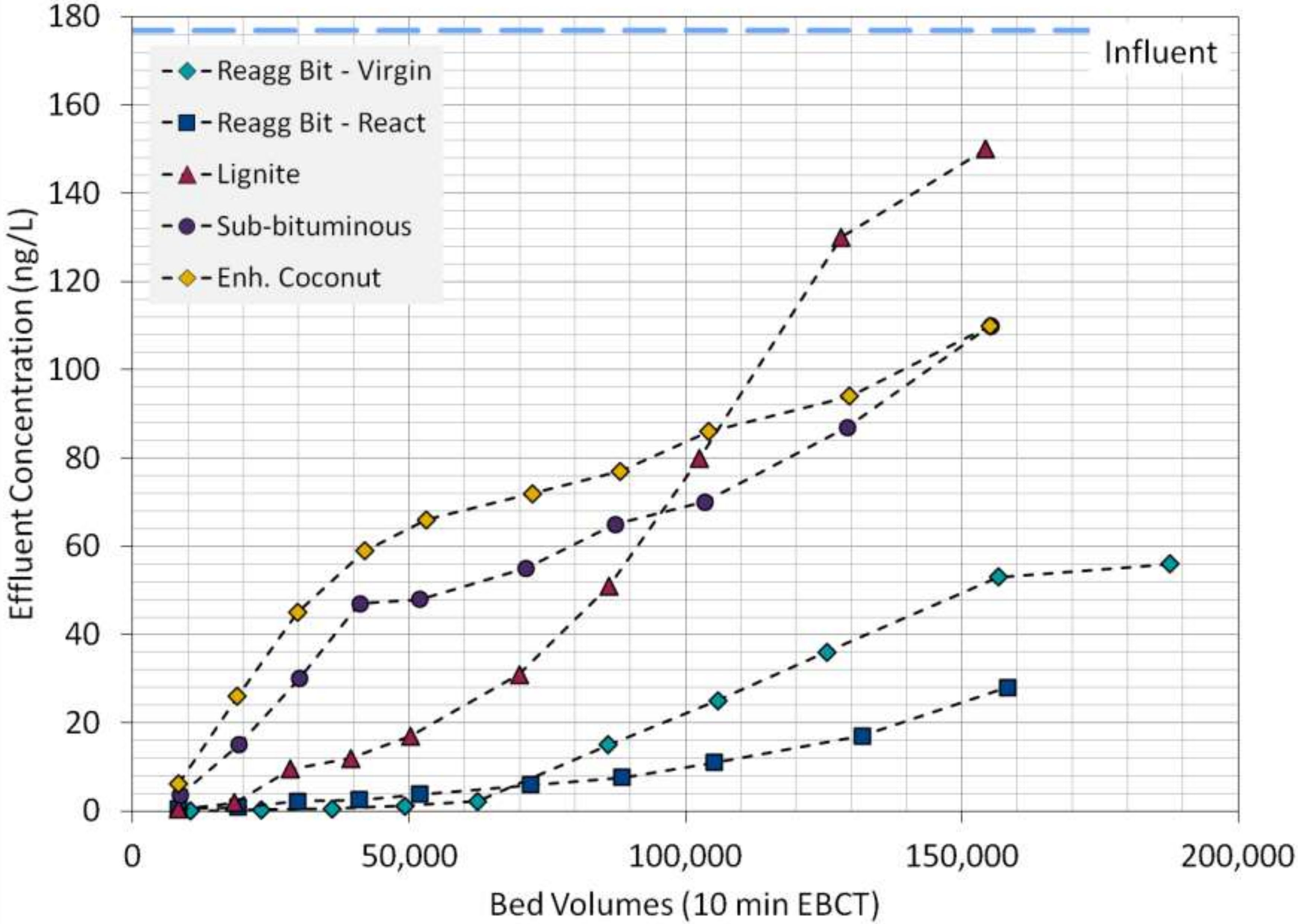
PFAS BREAKTHROUGH CURVES

PFOS



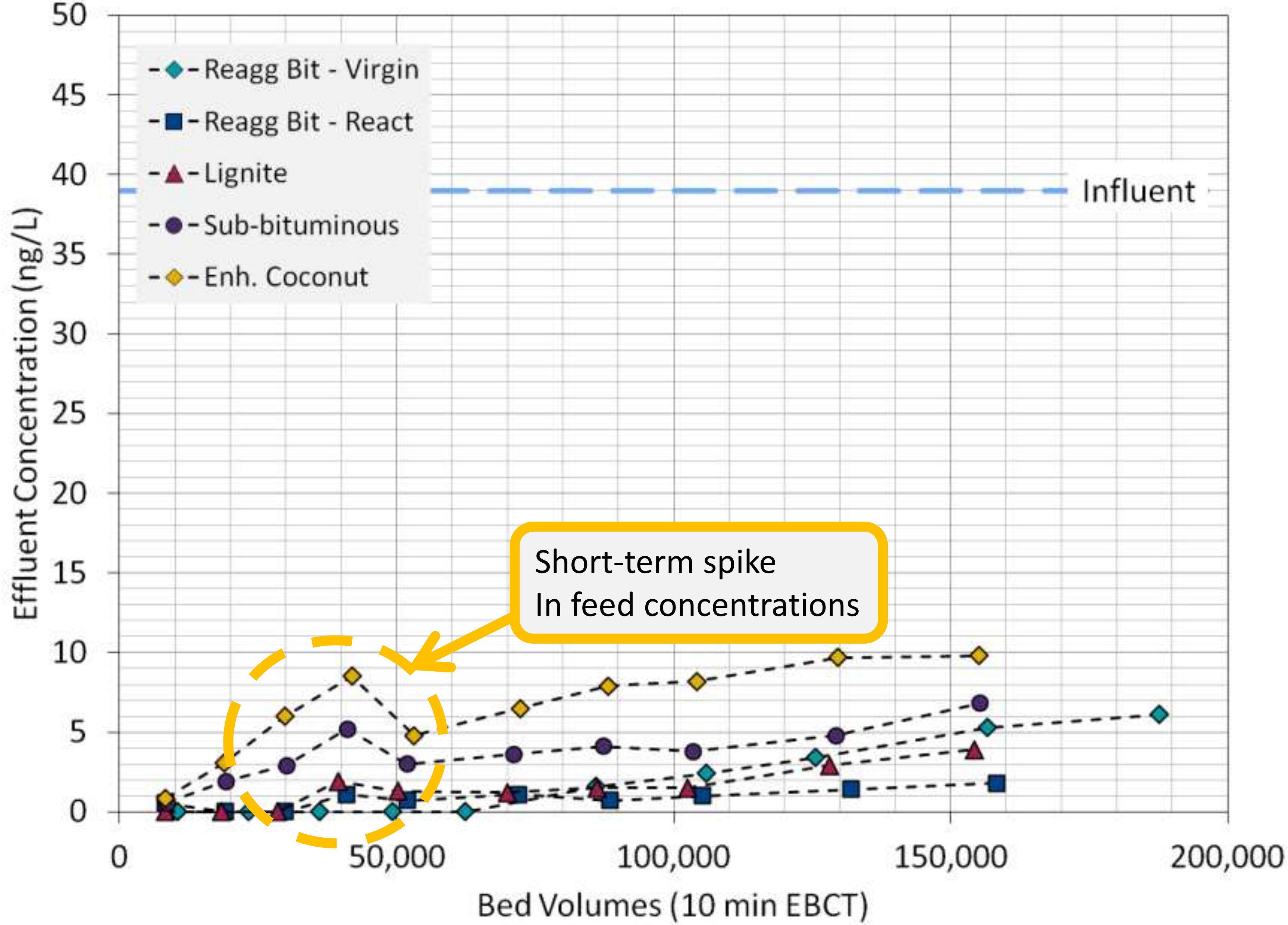
PFAS BREAKTHROUGH CURVES

PFOA



PFAS BREAKTHROUGH CURVES

PFOSA



INITIAL CONCLUSIONS

ALL 4 PRECURSORS REMOVABLE WITH GAC

- 4:2 FTS most difficult
  - Lower molecular weight (shorter chain).
  - Large variation in removal.
  - Most-favorable performance with reaggl. bituminous GACs.

SENSITIVITY TO VARYING INFLUENT CONCENTRATIONS

- Reaggl. bituminous GAC minimally affected.
- Sub-bituminous & enhanced coconut showed rapid increase in breakthrough during spike.
- Some sensitivity evident in lignite breakthrough curve.

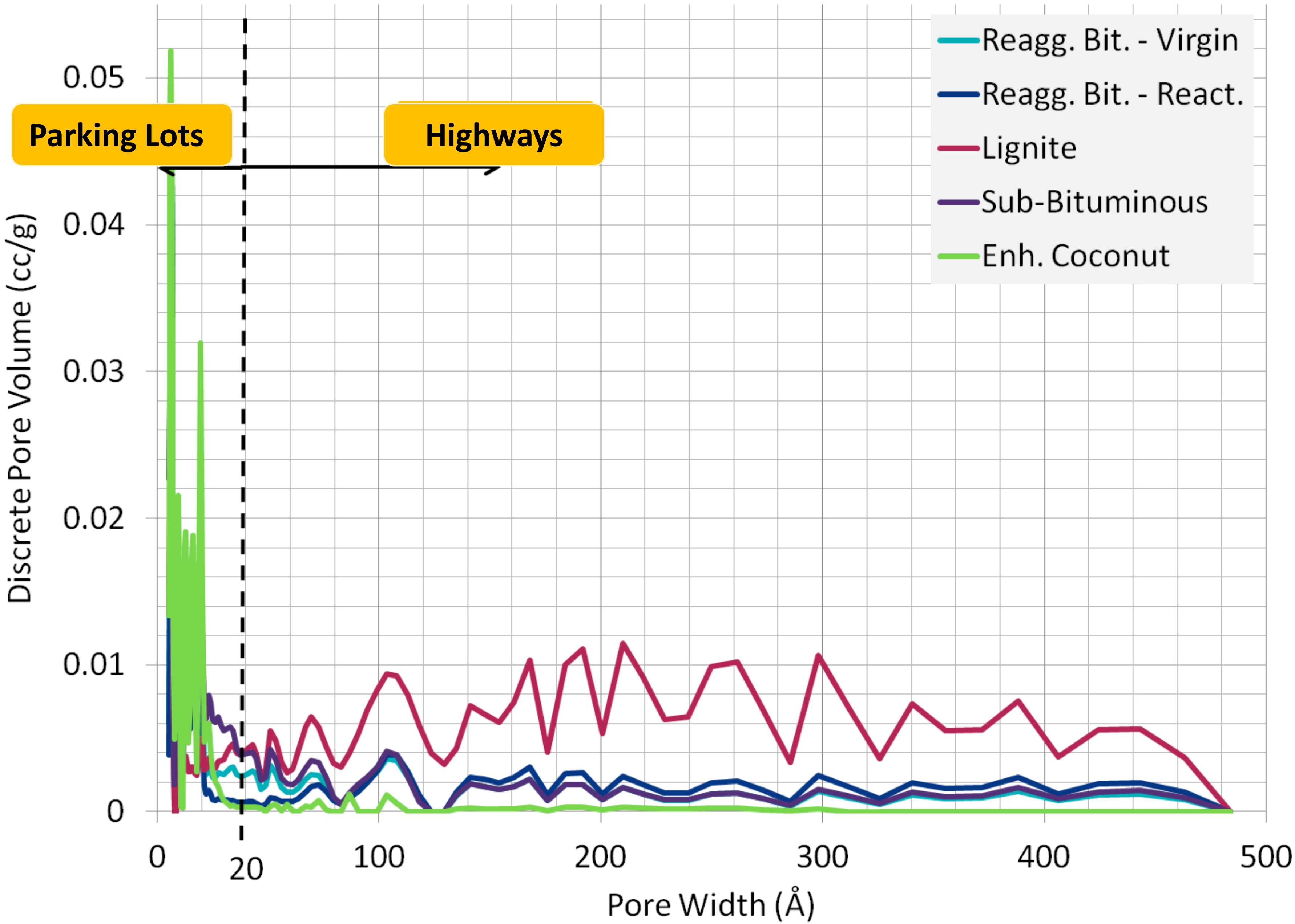
PROPERTIES vs. PERFORMANCE

4:2 FTS REMOVAL

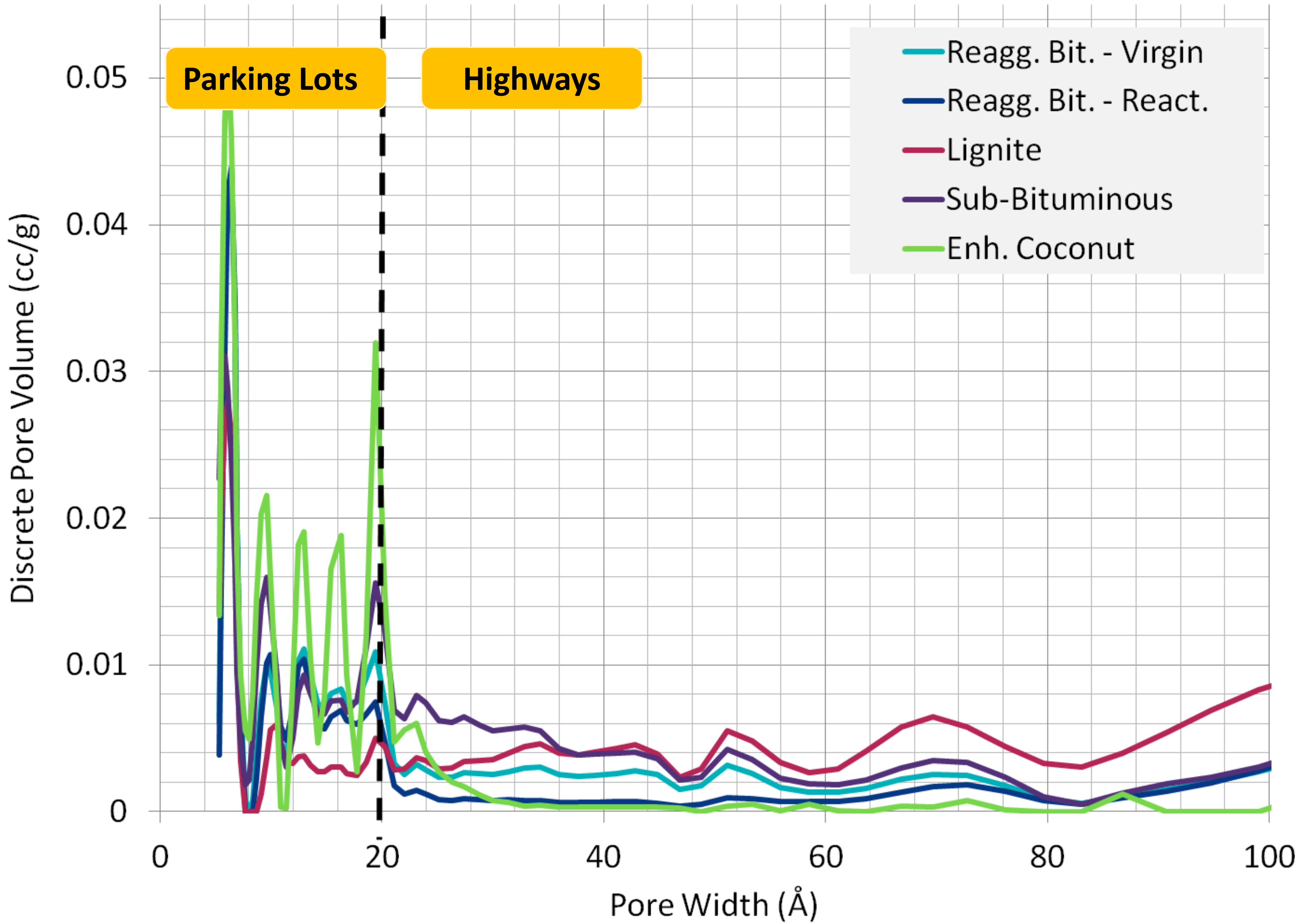
In addition to surrogate adsorbate tests, porosity of test GACs was evaluated using nitrogen adsorption isotherms and compared to performance.

GAC Source Material	BV to 50% Breakthrough	Apparent Density	Iodine Number (mg/g)	Xylenol Orange Dye Number (mg/g/hr)	Molasses Number
Reagglomerated Bituminous Coal - Virgin	206,300	0.543	1030	13.5	189
Reagglomerated Bituminous Coal – React.	150,500	0.546	905	13.4	236
Lignite Coal	36,200	0.377	605	17.4	416
Sub-Bituminous Coal	38,600	0.350	1015	21.7	154
Coconut Shell	38,800	0.414	1290	13.5	288

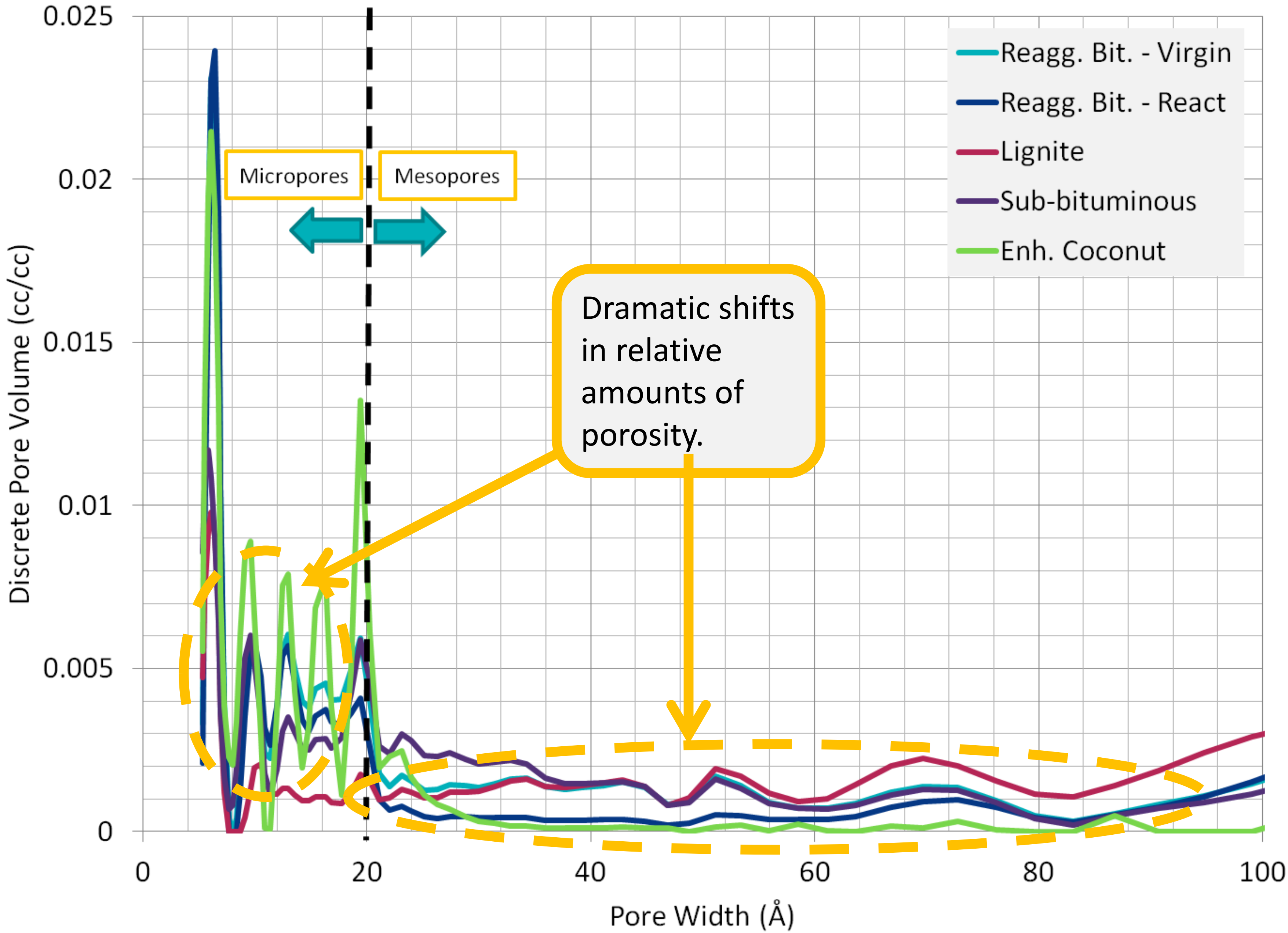
GAC POROSITY: ~5 - 500 Å



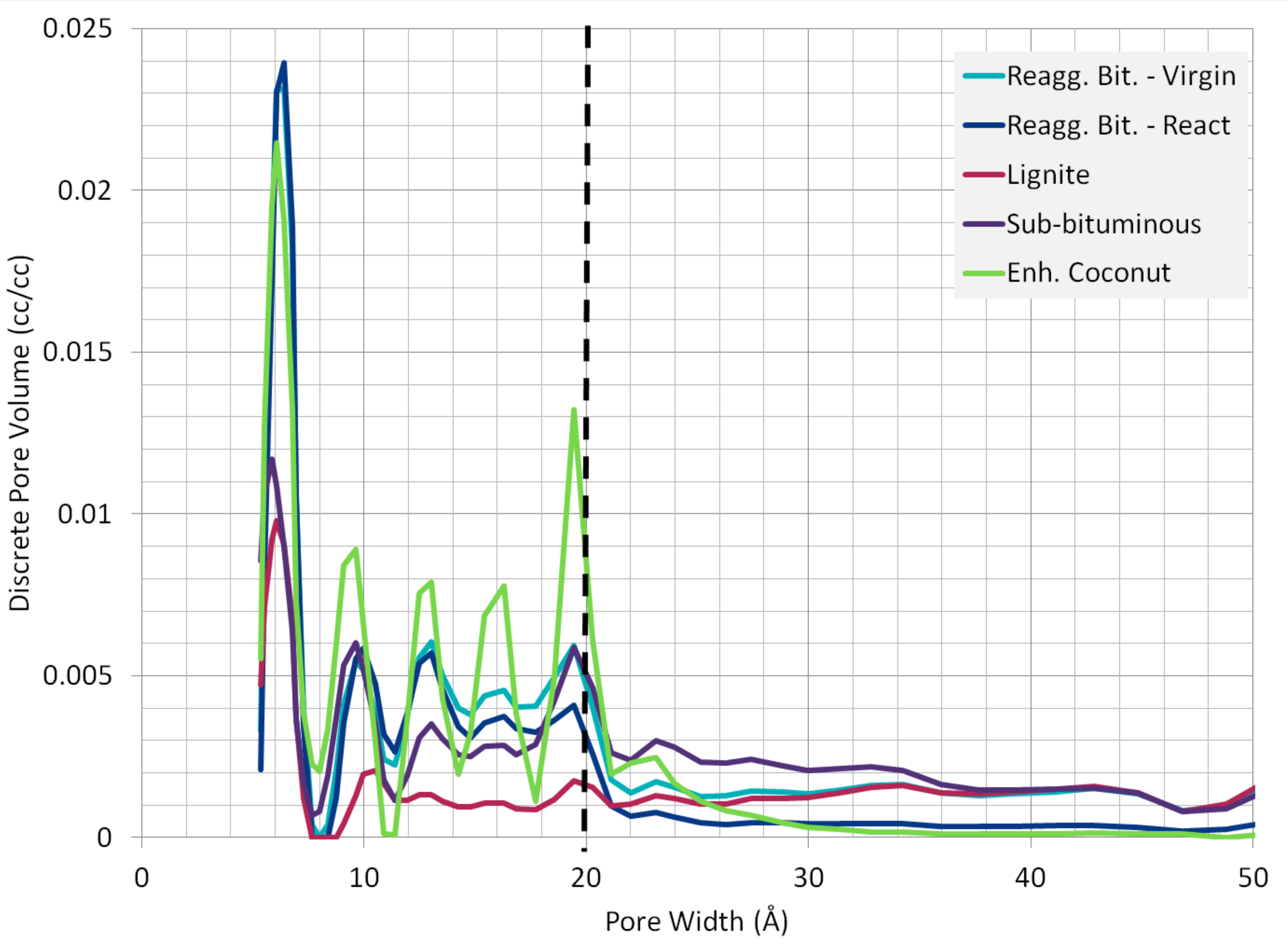
GAC POROSITY: ~5 - 100 Å



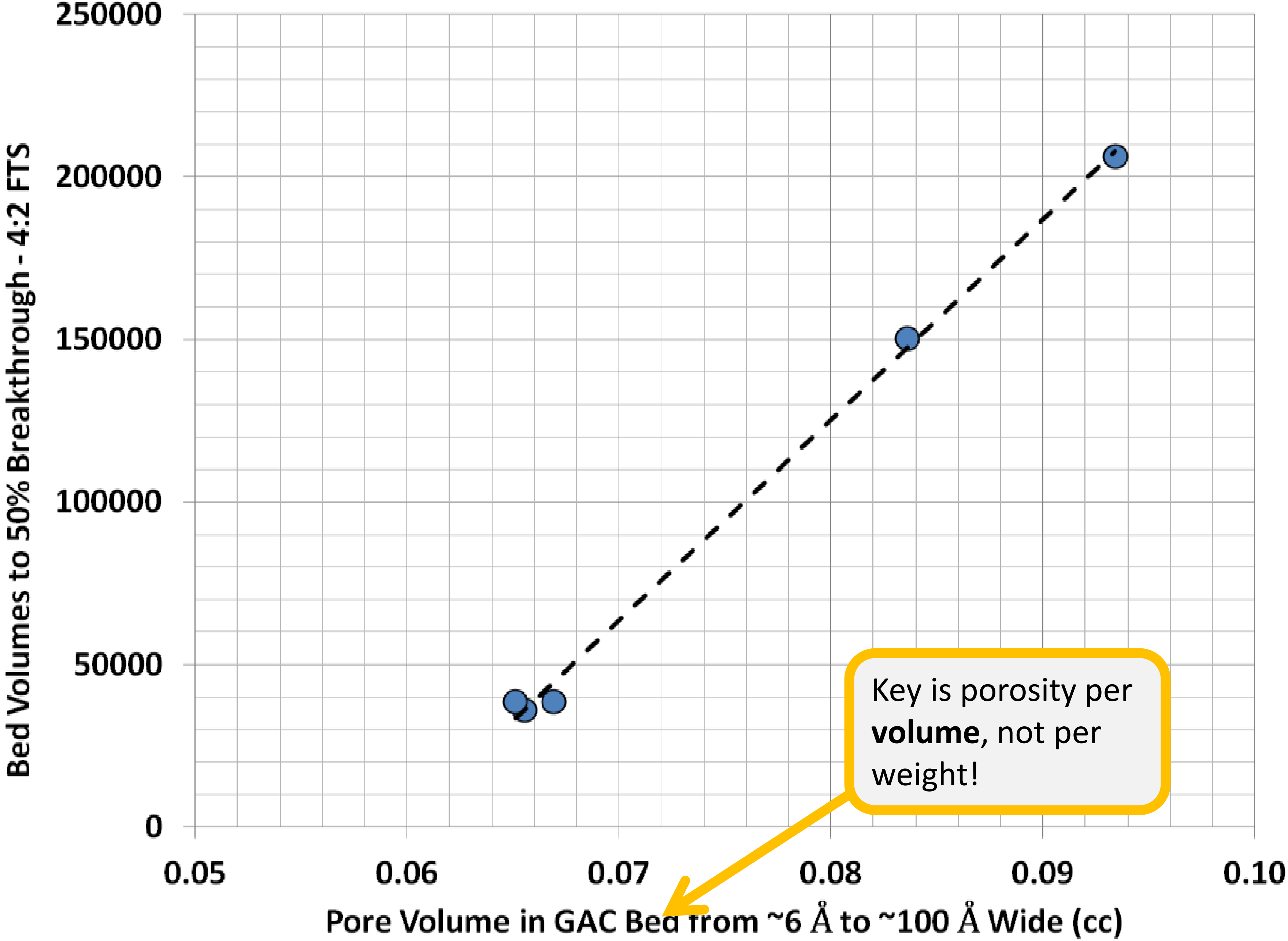
GAC POROSITY: NORMALIZED TO VOLUME IN BED



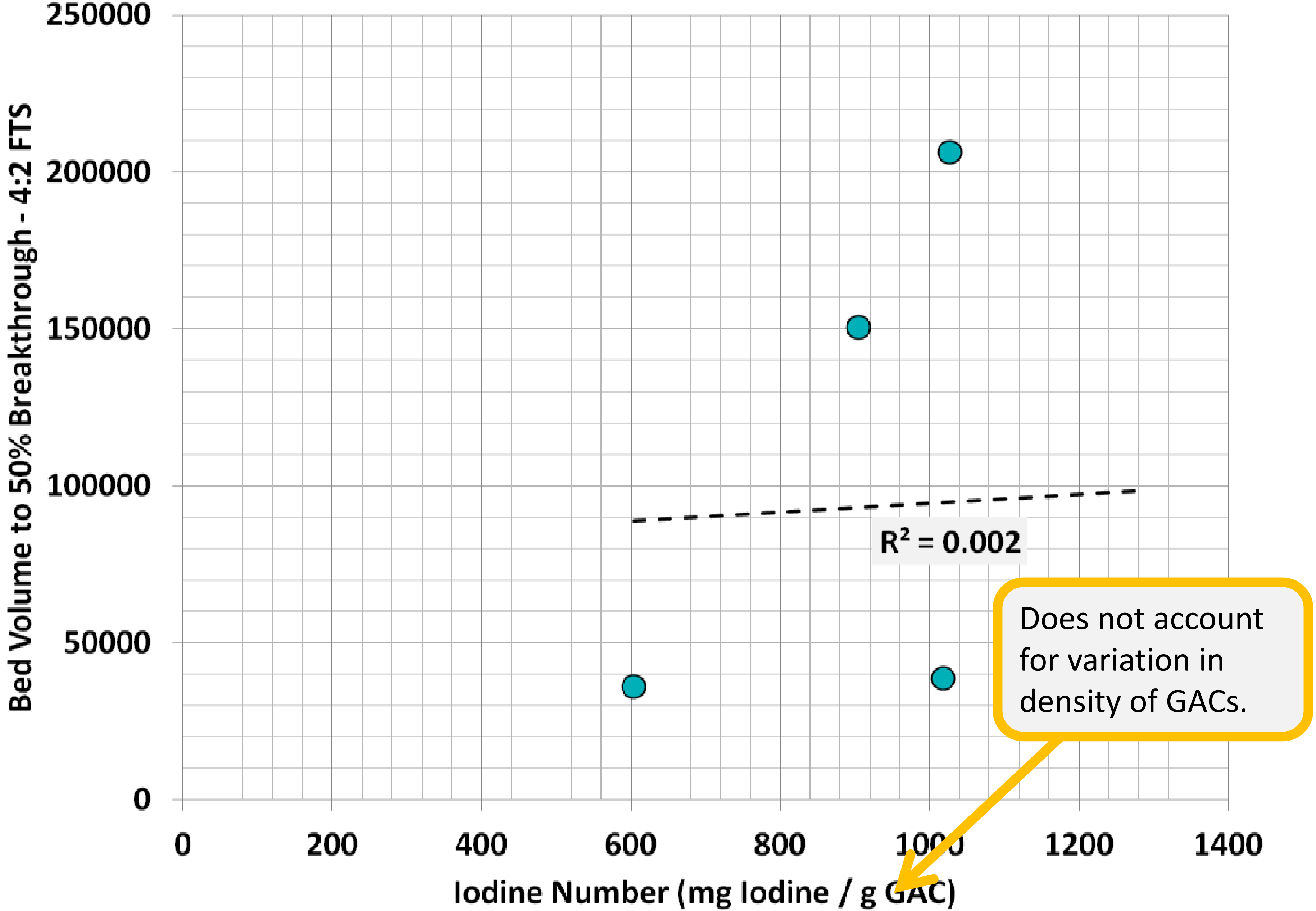
GAC POROSITY: HOW MUCH IS IN THE BED?



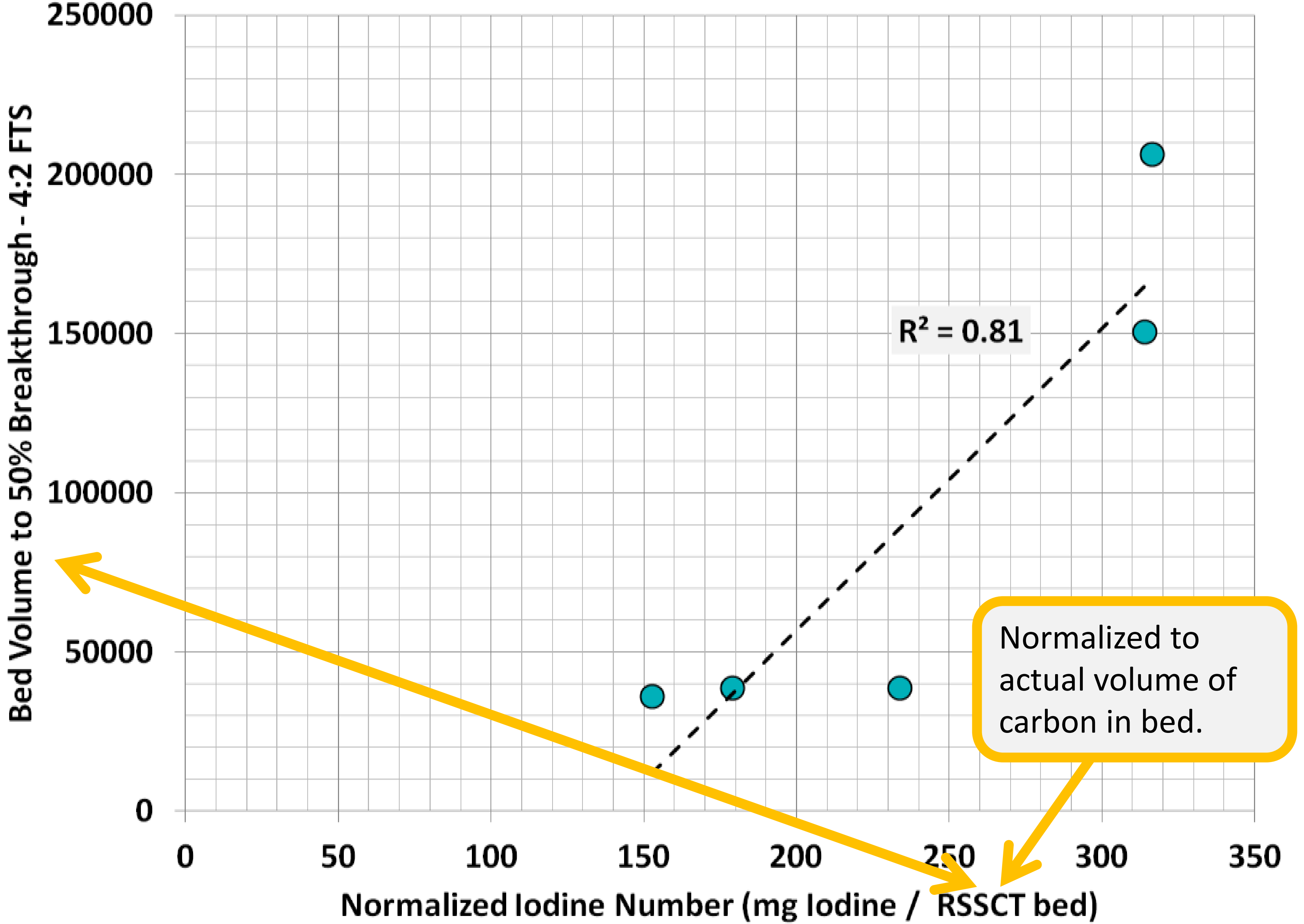
GAC POROSITY: RELATED TO PERFORMANCE?



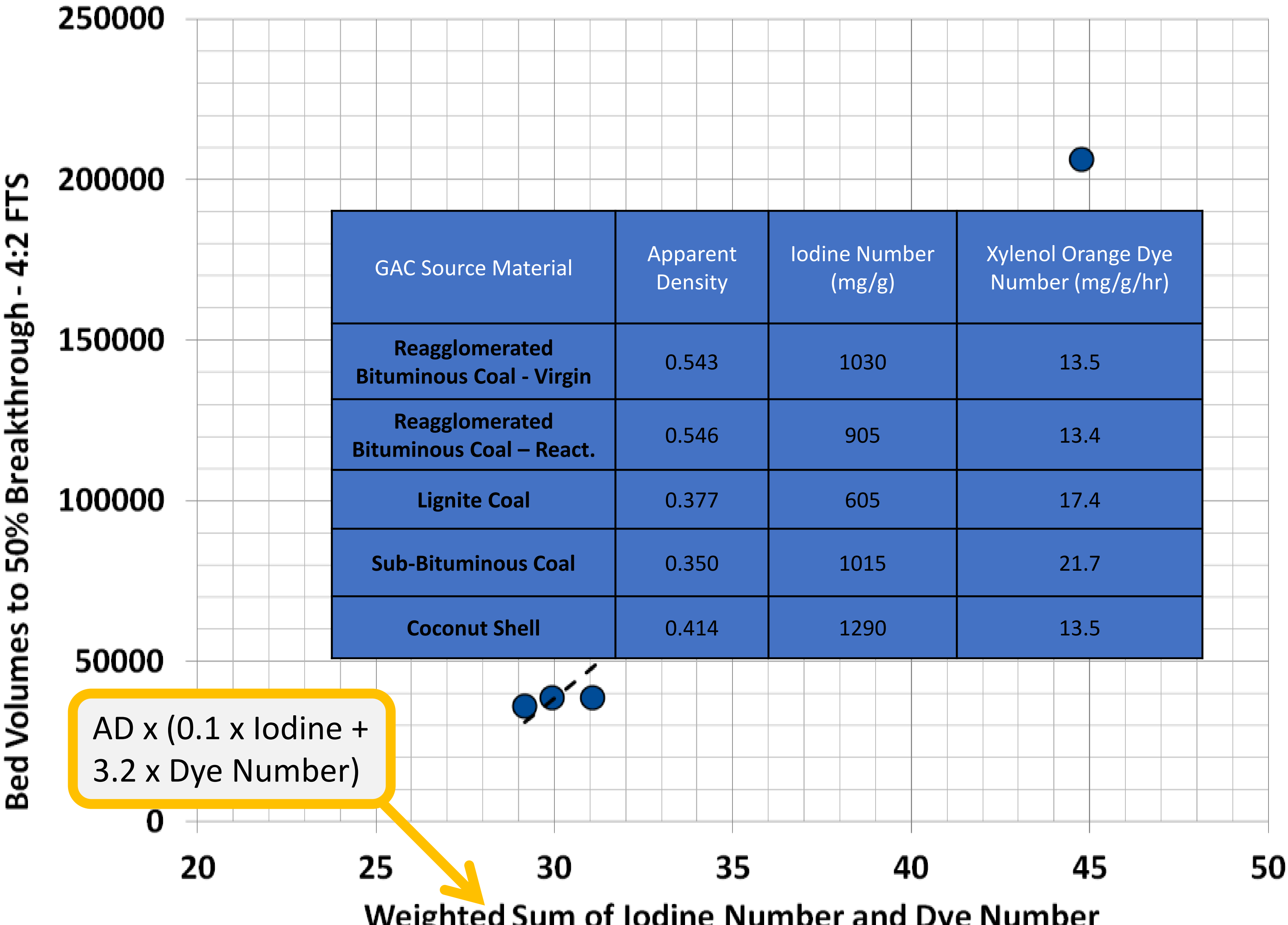
IODINE NUMBER: RELATED TO PERFORMANCE?



NORMALIZED IODINE NUMBER: RELATED TO PERFORMANCE?



IODINE & DYE NUMBER COMBINED: RELATED TO PERFORMANCE?



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CONCLUSIONS

PRECURSORS ARE REMOVABLE ALONG WITH PFOA & PFOS

- Compound structure impacts removal as expected
- GAC performance varies widely among source materials
- Reactivated GAC can offer performance on-par, or nearly on-par, with its virgin counterpart, depending on the target contaminant

GAC SELECTION MUST CONSIDER INTERPLAY BETWEEN PROPERTIES

- No single specification can adequately guide carbon selection
- Porosity is key, but only when considered alongside bed density
- “Old” methods such as Iodine Number are still valuable, especially when combined with some measure of adsorption rate, such as Dye Number

Thank you for your time.
Questions?

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