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- Fulbright Scholar of Aalborg University of Denmark
- Senior Sustainability Scientist at Global Institute of Sustainability and Innovation
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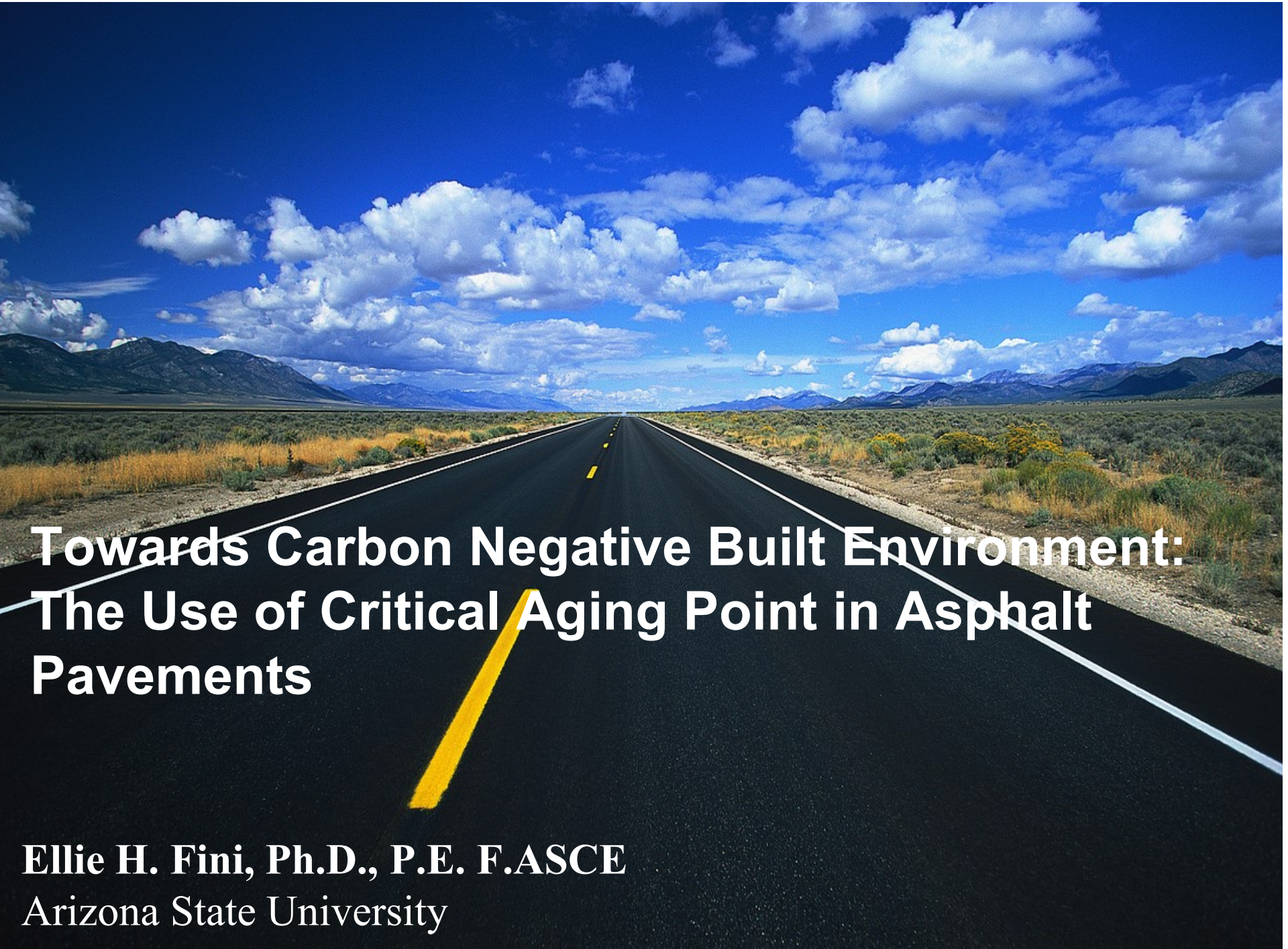
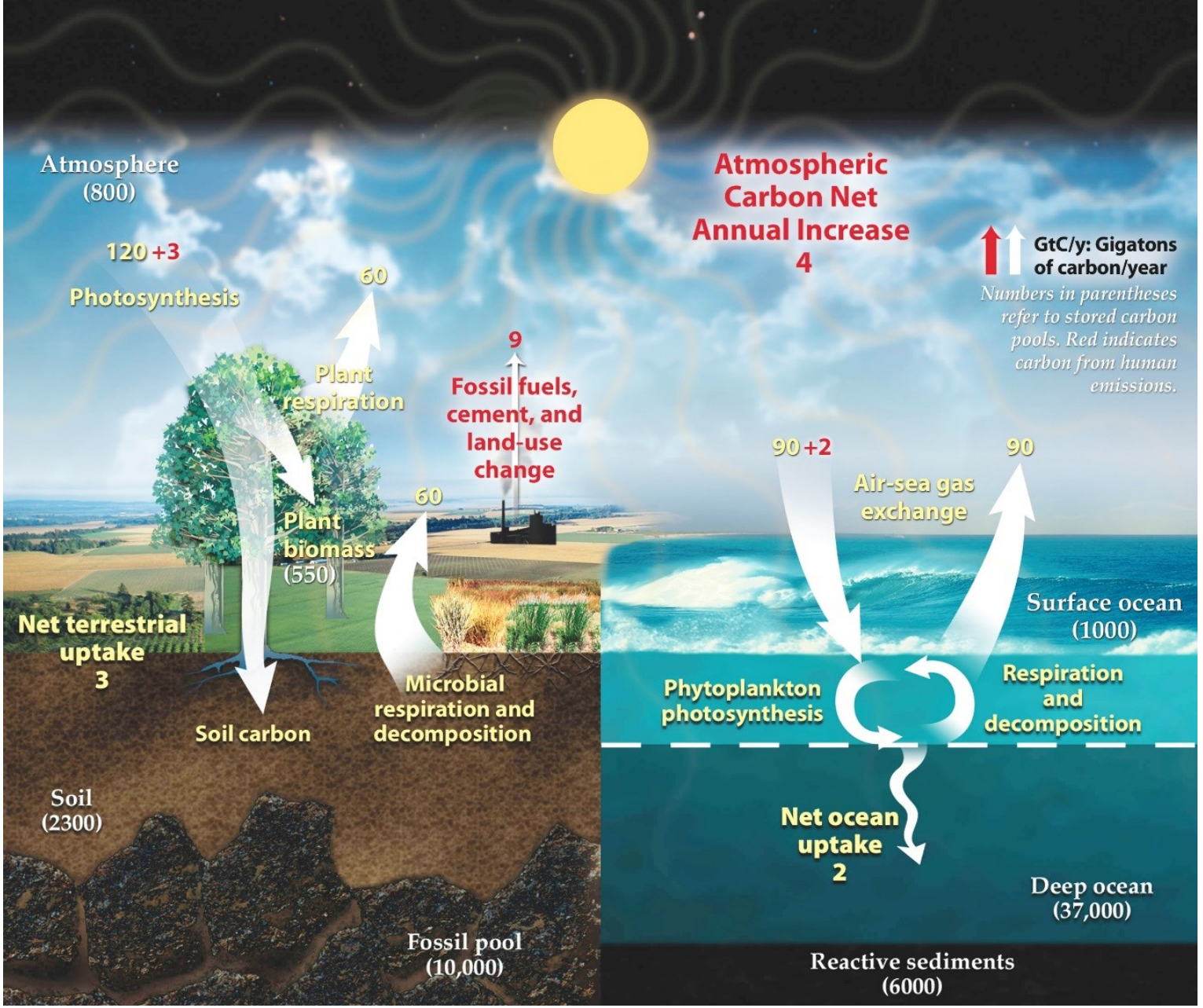
https://isearch.asu.edu/profile/3333499



Towards Carbon Negative Built Environment: The Use of Critical Aging Point in Asphalt Pavements

Ellie H. Fini, Ph.D., P.E. F.ASCE
Arizona State University



Fundamentals of Building Construction: Materials and Methods, Allen, E., Iano, J., ISBN-9781119446194

Carbon & Pavements!?

- Energy usage per lane mile of pavement typically ranges from 3-7TJ (equivalent to yearly energy consumption of *41 U.S. household*, 0.1 TJ/year/household)

- CO_2 emissions per lane mile of pavement construction is equivalent to yearly carbon emissions of *20 U.S. household*

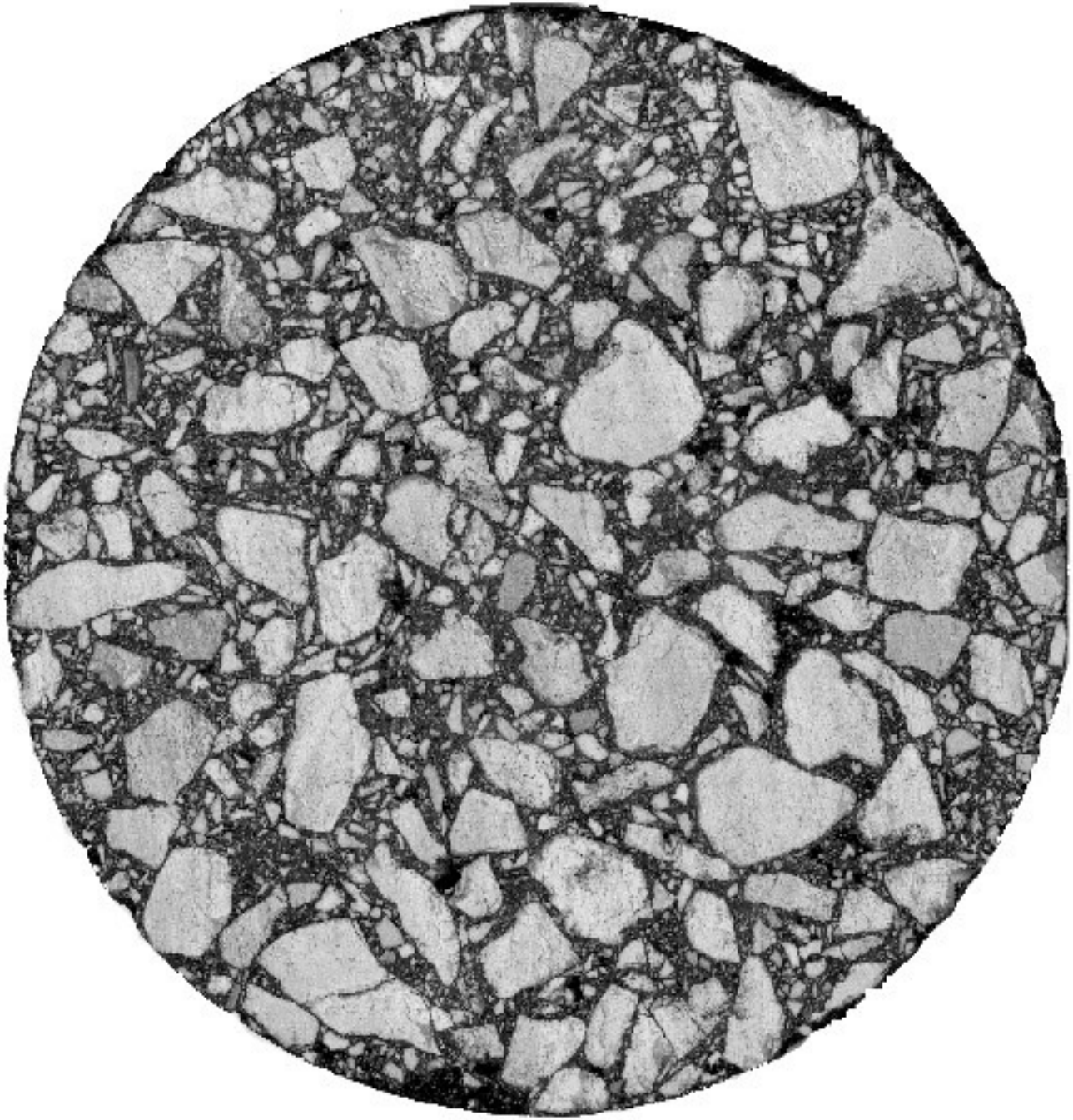
- With more than 4millon miles of roads in the US, pavements account for about 70% of state and local $100B roadway expenditures[1]

[1]*Muench, Transportation Research Record, 2010, pp. 36-45*

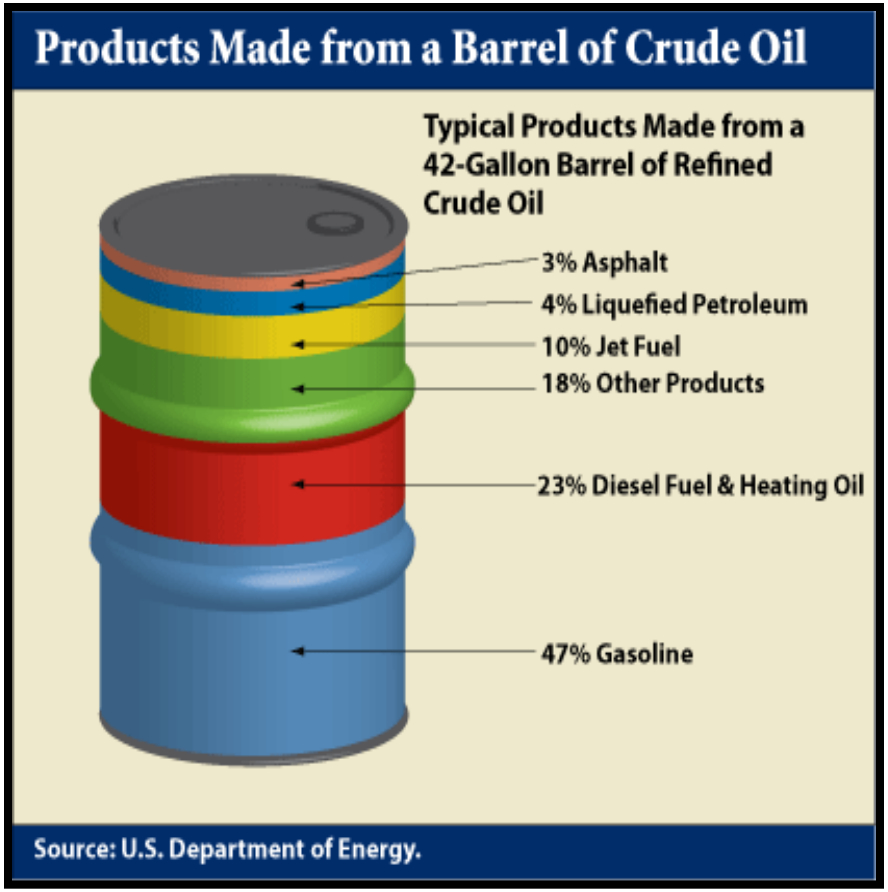
Sustainability in Roadway Construction

- Pavement Construction
  - Material Production
  - Construction Process
  - Transportation associated with construction
  - Maintenance

	Energy	CO_2
Material Production	**70**	**75**
Construction	**5**	**5**
Transportation	**20**	**10**
Maintenance	**5**	**10**



Binder Source?

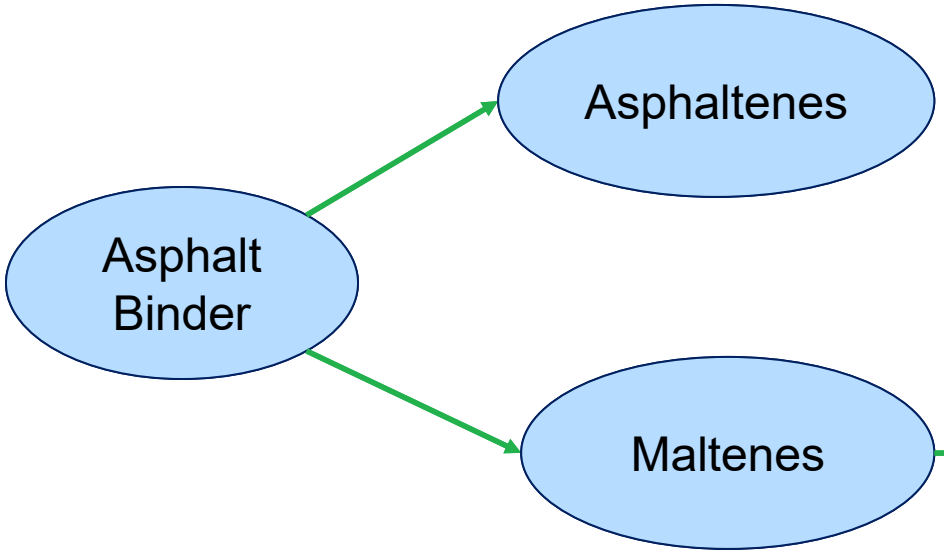


Basic properties of bio-binders*

Properties	CO	CS	MS	WP	WVO
Density (g/cm^3)	0.881	1.250	1.050	1.230	0.898
C (%)	77.80	61.6	65.77	61.05	77.30
H (%)	12.66	7.28	7.31	6.93	12.08
O (%)	9.46	30.16	26.25	31.81	10.50
N (%)	0.08	0.96	0.67	0.21	0.12
Saturates (%)*	20.95	6.8	6.22	3.46	0.00
Aromatics (%)*	0.00	3.73	8.56	2.93	87.19
Resins (%)*	78.17	67.49	60.47	76.21	12.80
Asphaltenes (%)*	0.87	21.96	24.47	17.38	0.00

*Zhou, T., F. Kabir, L. Cao, E. H. Fini, 2021, Journal of Resources, Conservation & Recycling, https://doi.org/10.1016/j.resconrec.2021.105626

Composition of Asphalt Binder



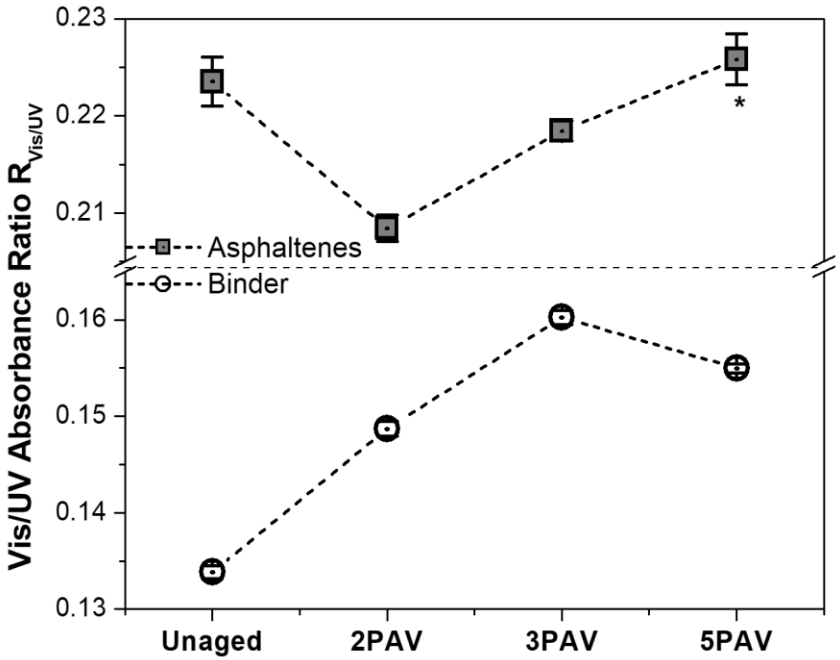
- Polar compounds (Resins)
- Aromatics (Napthene aromatics)
- Saturated hydrocarbons

Polarity: Asphaltenes >> Resins > Aromatics | Saturates

Hung, A. and E. H. Fini, 2019, Absorption spectroscopy to determine the extent and mechanisms of aging in bitumen and asphaltenes, *Fuel* 242: 408-415

Asphalt Compounds Age Differently

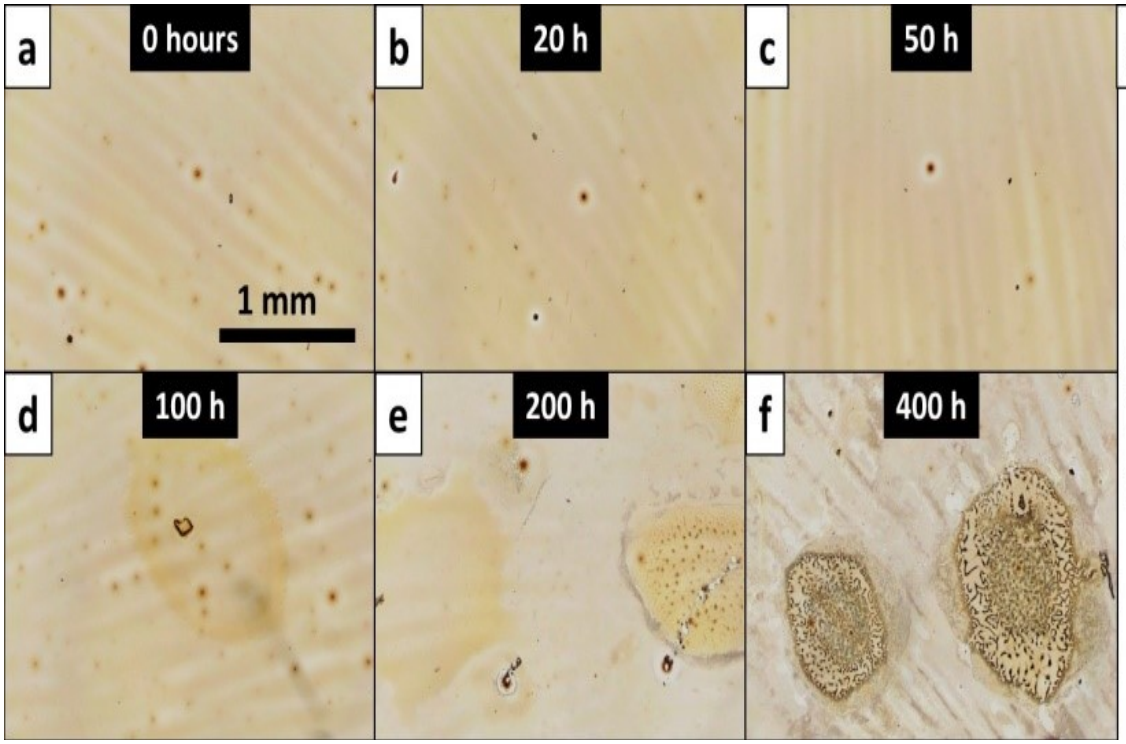
- How asphalt binder constituents react with oxygen defines asphalt susceptibility to oxidation.

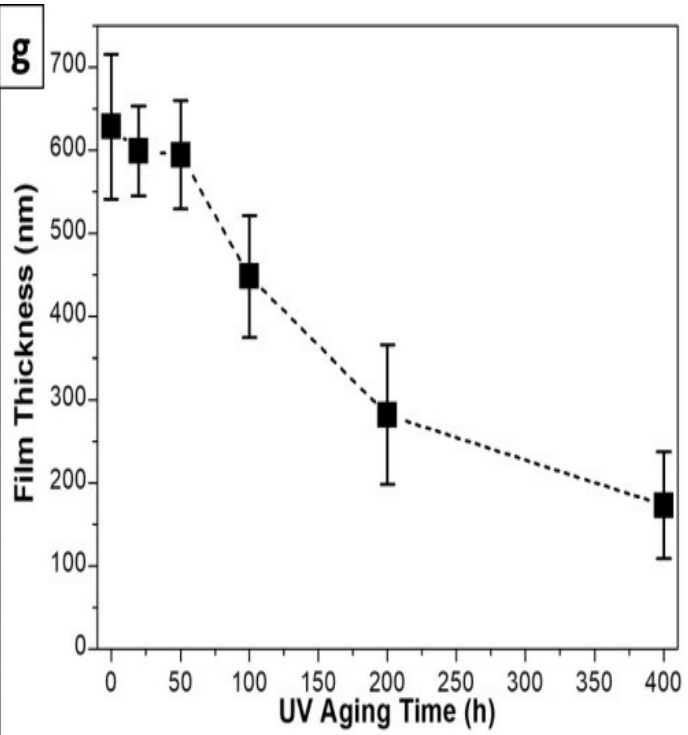


%	Unaged	2PAV	3PAV	5PAV
Saturates	12	10	10	2
Aromatics	19	17	36	7
Resins	50	45	23	62
Asphaltenes	19	28	30	29

Hung, A. and E. H. Fini, 2019, Absorption spectroscopy to determine the extent and mechanisms of aging in bitumen and asphaltenes, *Fuel* 242: 408-415.

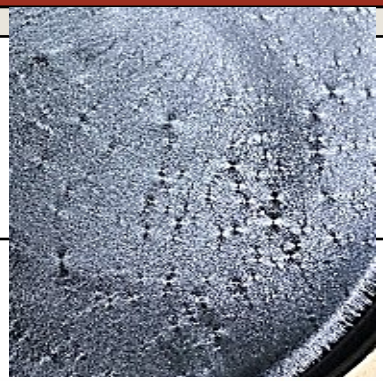
Asphalt Changes Due to Aging

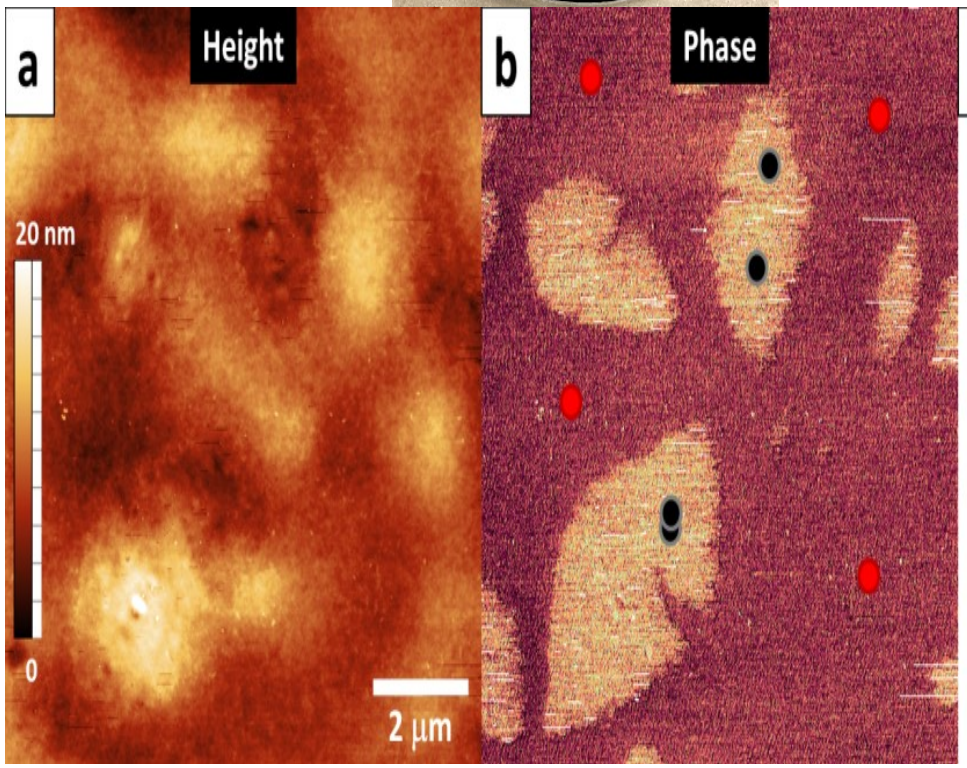


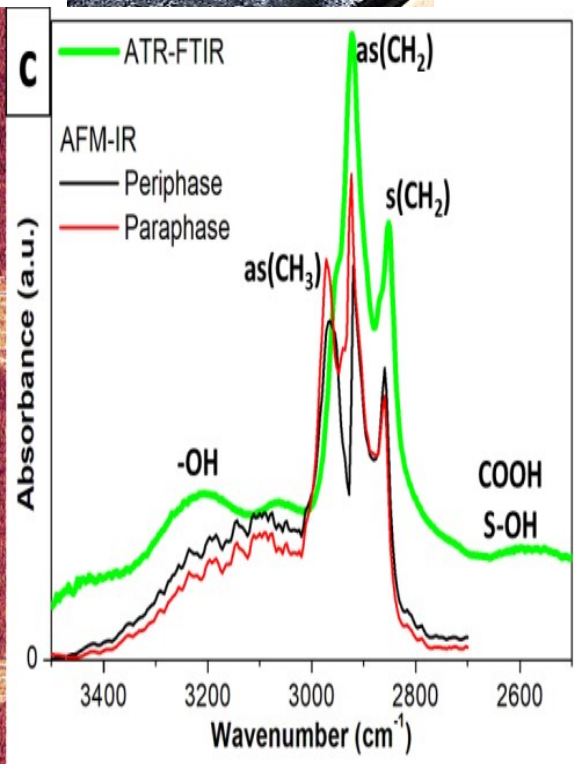


Hung, A., and E. H. Fini, 2020, Surface Morphology and Chemical Mapping of UV-Aged Thin Films of Bitumen, *ACS Sustainable Chemistry & Engineering*, doi.org/10.1021/acssuschemeng.0c03877

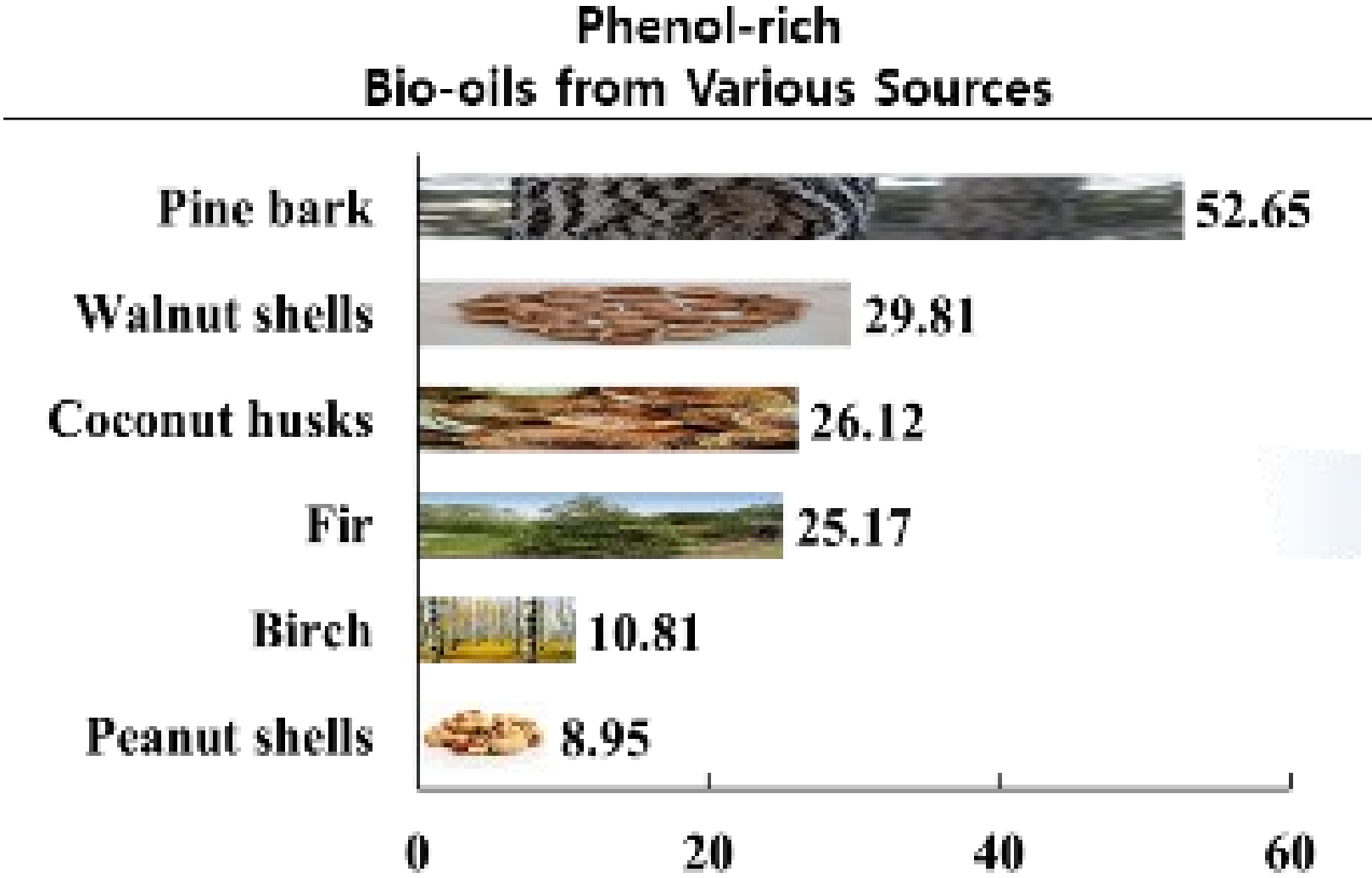
Solution 1: Delay Aging







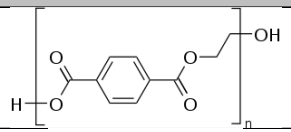
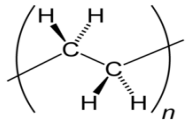
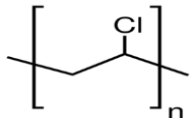
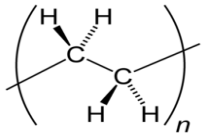
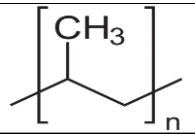
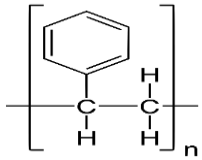
Hung, A., and E. H. Fini, 2020, Surface Morphology and Chemical Mapping of UV-Aged Thin Films of Bitumen, ACS Sustainable Chemistry & Engineering, doi.org/10.1021/acssuschemeng.0c03877



Park, K-B. J-S Kim, F. Pahlavan, E. Fini, 2022, Biomass Waste to Produce Phenolic Compounds as Antiaging Additives for Asphalt, ACS Sustainable Chem. Eng. 2022, 10, 12, 3892–3908, https://doi.org/10.1021/acssuschemeng.1c07870

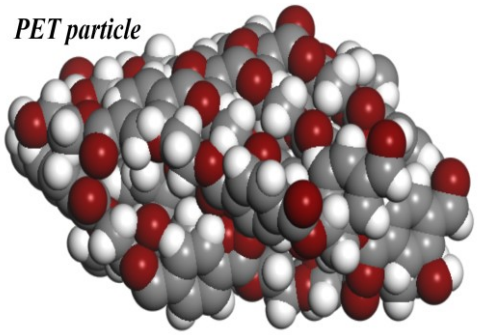
Waste plastic: a carrier for bio-oil

- Not all types of plastics are equally recyclable
- Polyethylene Terephthalate (PET) and High-density Polyethylene (HDPE) are the most widely used plastics.
- PET can undergo monomer recycling and mechanical recycling.

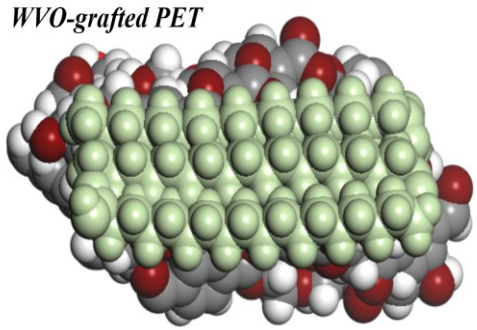
Polymer name Symbol	Chemical structure	Uses	Can be recycled
polyethylene terephthalate 1 PET		soda bottles, water bottles, medicine jars, and salad dressing bottles	yes
high-density polyethylene 2 HDPE		soap bottles, detergent, and bleach containers, and trash bags	yes
polyvinyl chloride 3 PVC		plumbing pipes, cables, and fencing	limited
low-density polyethylene 4 LDPE		cling wrap, sandwich bags, and grocery bags	limited
Polypropylene 5 PP		reusable food containers, prescription bottles, and bottle caps	limited
Polystyrene 6 PS		plastic utensils, packaging peanuts, and Styrofoam	no
other plastics (e.g., acrylic, polycarbonate, etc.) 7 Other	–	water cooler bottles, baby cups and fiberglass	no

Kabir et al, 2021, End of Life Plastics to Enhance Sustainability of Pavement Construction Utilizing a Hybrid Treatment of Bio-Oil and Carbon Coating, *Construction and Building Materials*

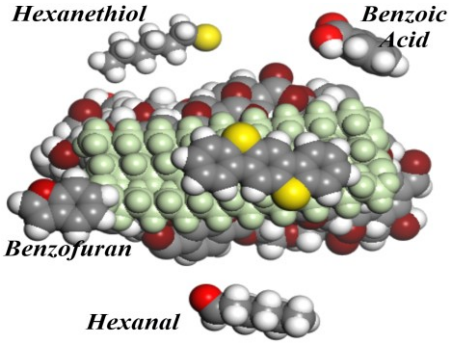
Delay Asphalt Aging with Bio-grafted PET



polyethylene terephthalate (PET) particle

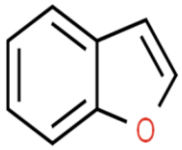


Binding of a molecular assembly of waste vegetable oil (WVO) on the PET surface (WVO-grafted PET)

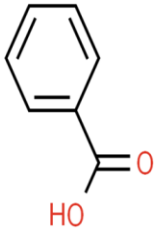


WVO-grafted PET surrounded by some volatile organic compounds.

Delay Asphalt Aging with Bio-grafted PET

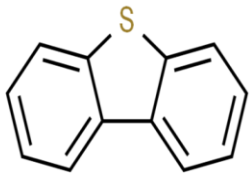


Benzofuran

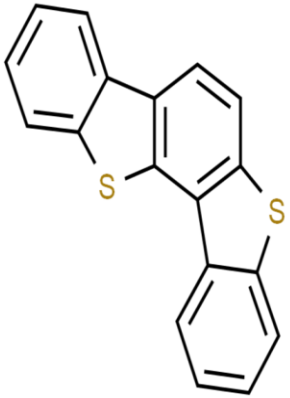


Benzoic acid

Hexanal

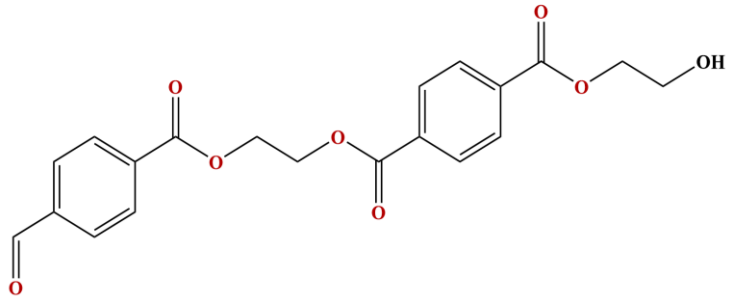


Dibenzo-thiophene



Benzo[1,2-b:4,5-b0]bis[b] benzothiophene

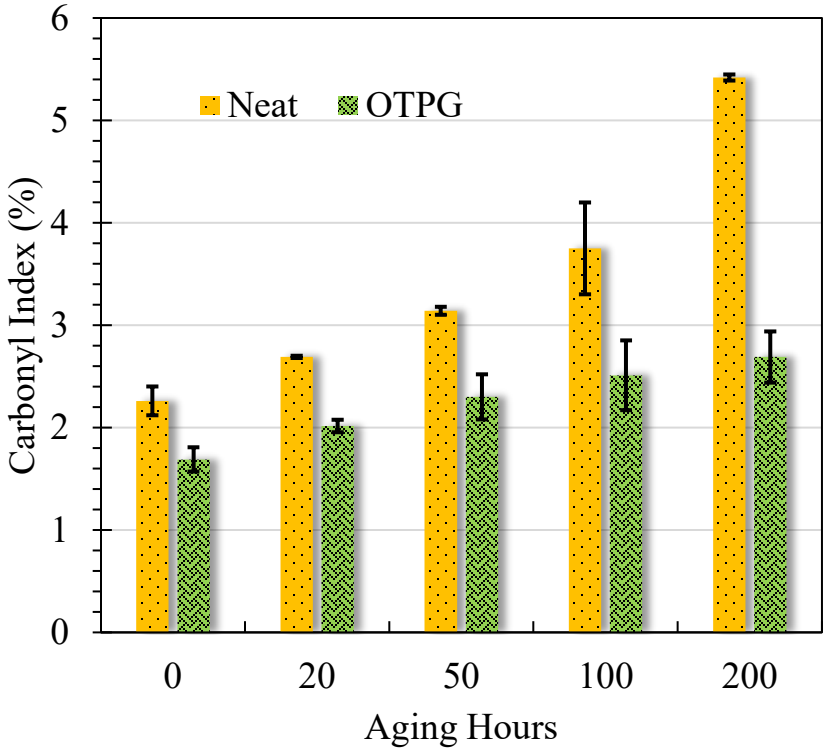
Hexanethiol

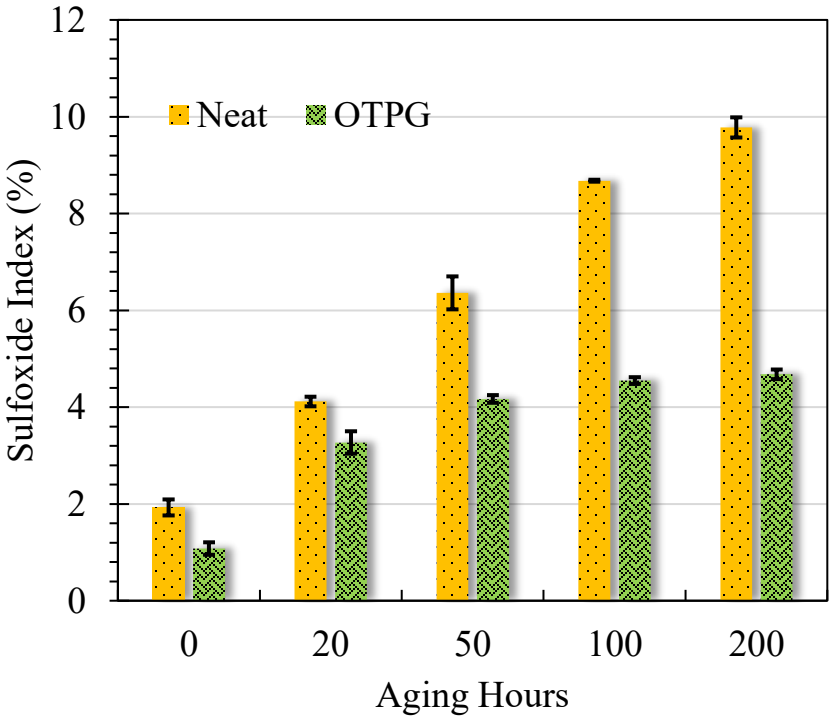


Molecular structure of a PET thermoplastic model containing two repeating units used in this study.

volatile compounds of bitumen

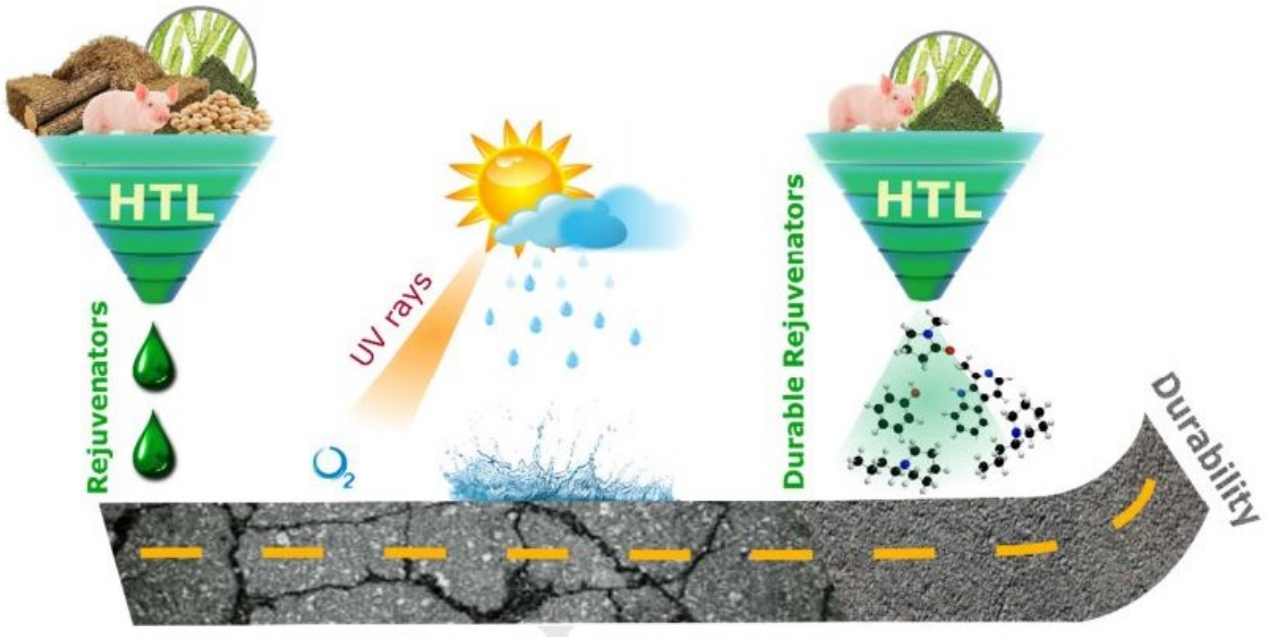
Bio-grafted PET granules delay aging





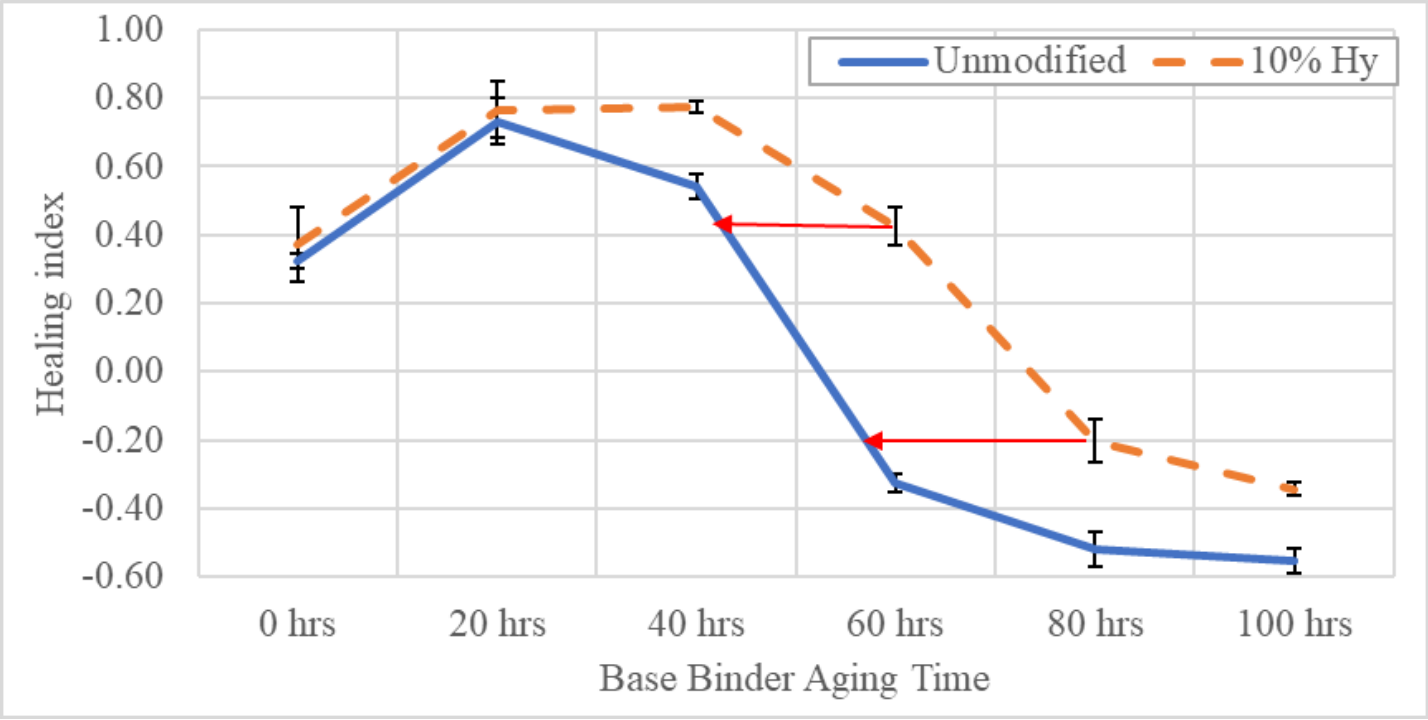
Mousavi, and E. H. Fini, 2021, Preventing Emission of Hazardous Organic Compounds from Bituminous Composites Using Functionalized Polyethylene-Terephthalate, *Journal of Cleaner Production,* https://doi.org/10.1016/j.jclepro.2022.131067

Solution 2: Rejuvenation



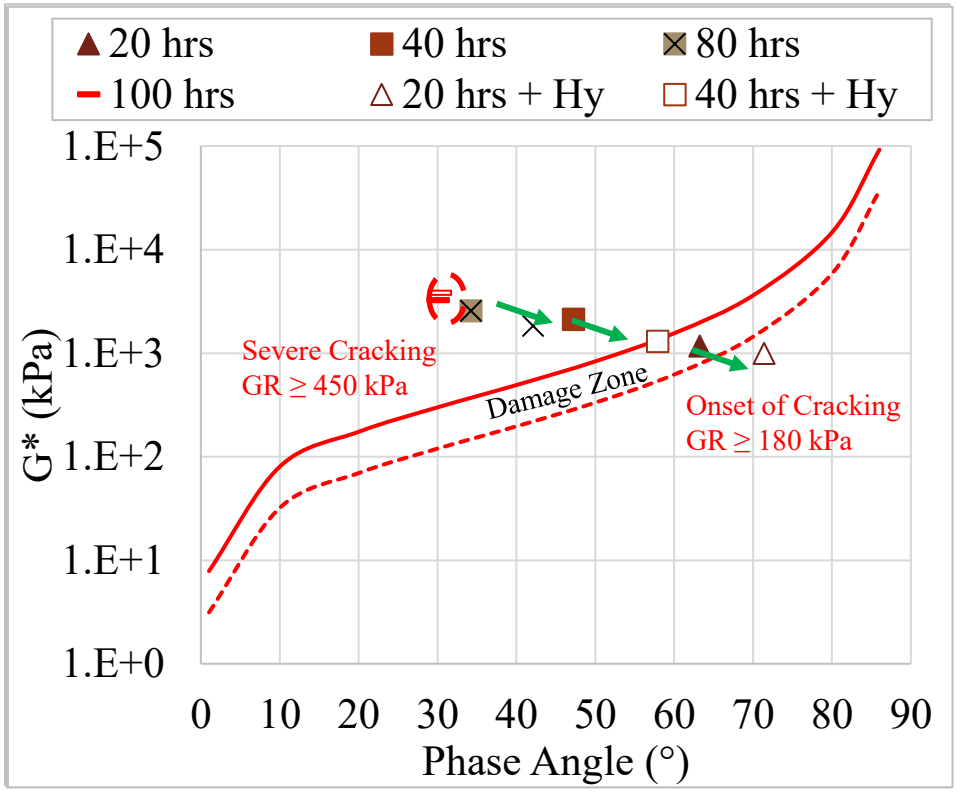
Why Do We Need Rejuvenator?

it enhances healing capacity …

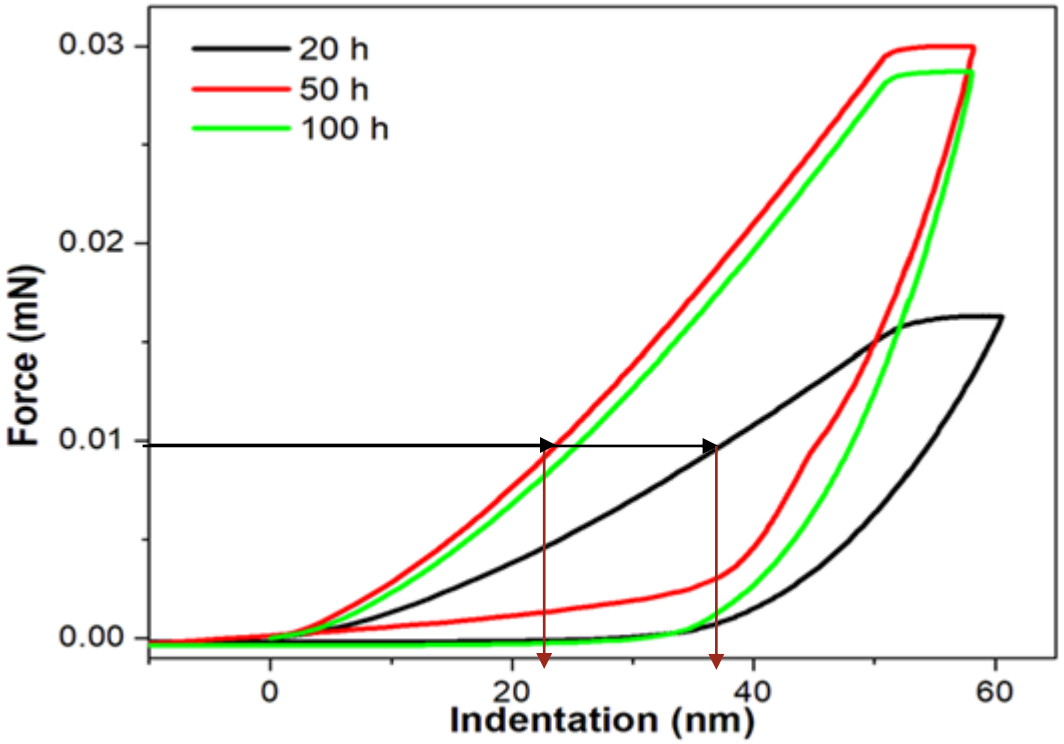


Why Do We Need Rejuvenator?

it enhances cracking resistance…

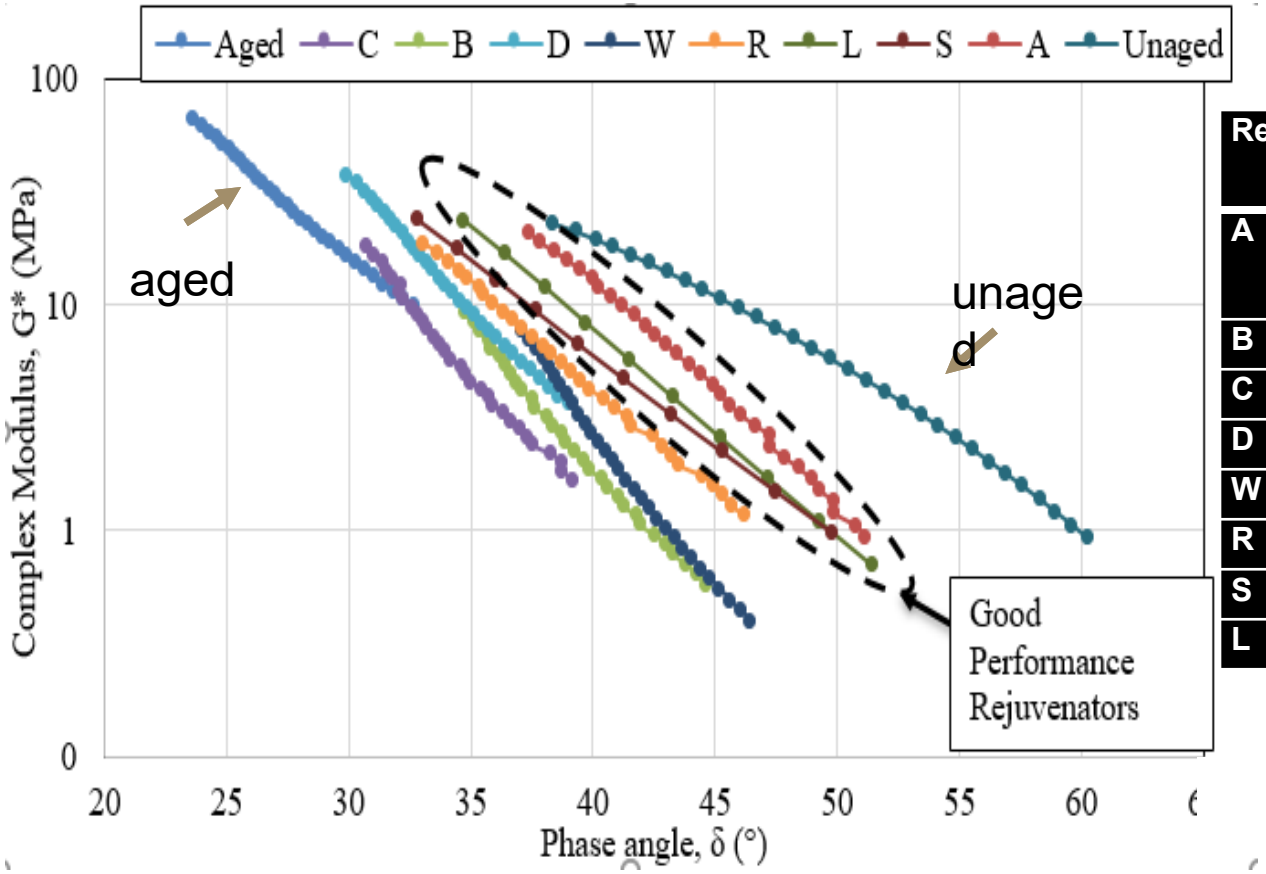


Aged Asphalts React Differently to Loading



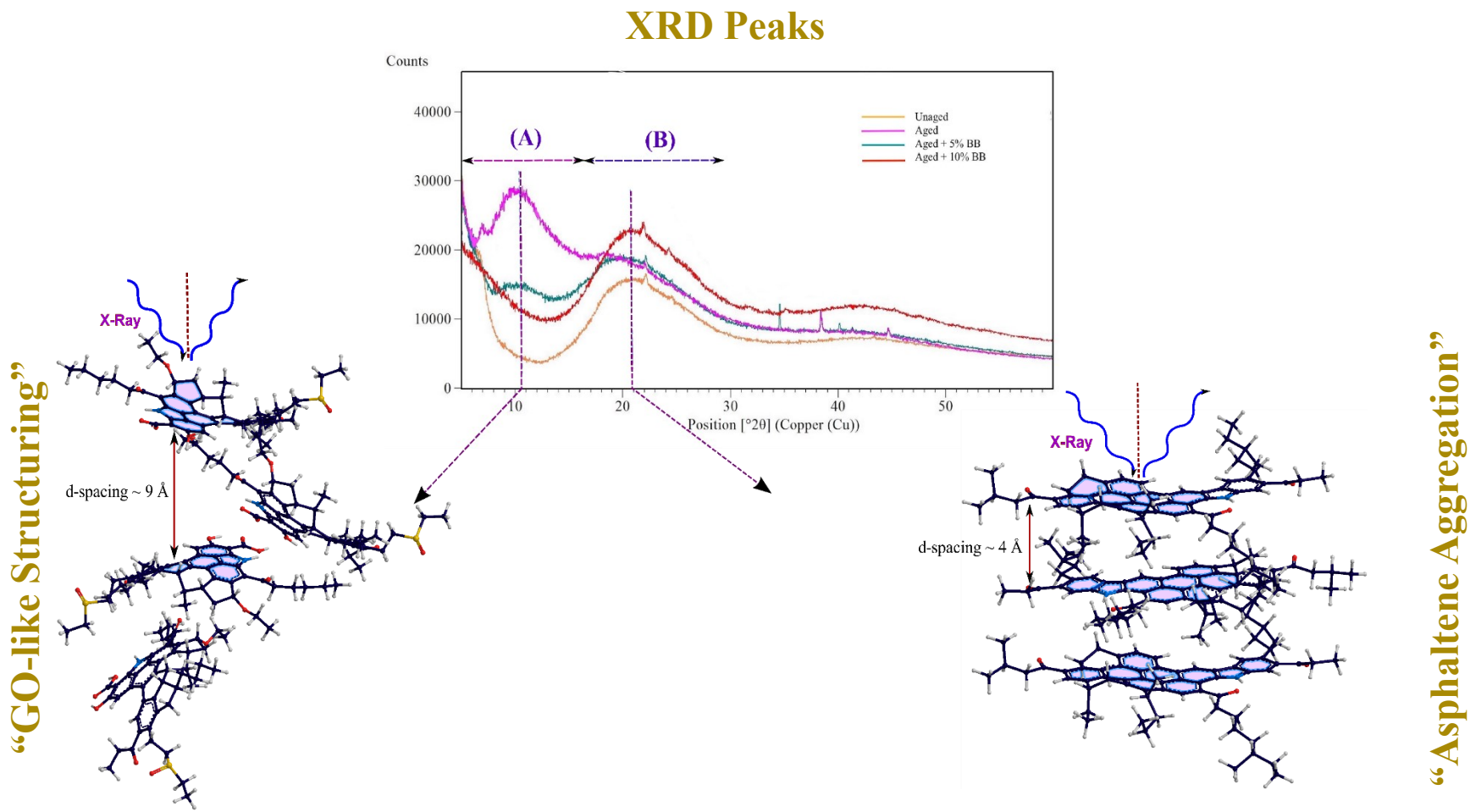
Hung, A. M., M., Kazembeyki, Ch. G. Hoover, E. H. Fini, 2019, Evolution of Morphological and Nanomechanical Properties of Bitumen Thin Films as a Result of Compositional Changes Due to Ultraviolet Radiation, *ACS Sustainable Chemistry & Engineering*.

How do we know which rejuvenator is right?



Rej	Source
A	plant extract (rosin, fatty acid, vegetable oil)
B	vegetable oil
C	soy-based oil
D	petroleum-based
W	waste vegetable oil
R	rubberwood oil
S	swine manure
L	algae

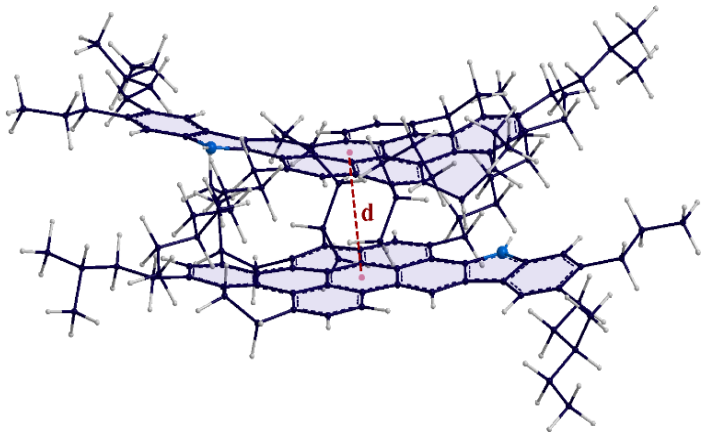
Schematic Representation of the Oxidized Agglomerates



Pahlavan, F., A. Hung, and E. H. Fini, 2018, Evolution of Molecular Packing and Rheology in Asphalt Binder during Rejuvenation, *Fuel,* 222: 457-464

Aging Promotes Agglomeration of Asphaltenes

25



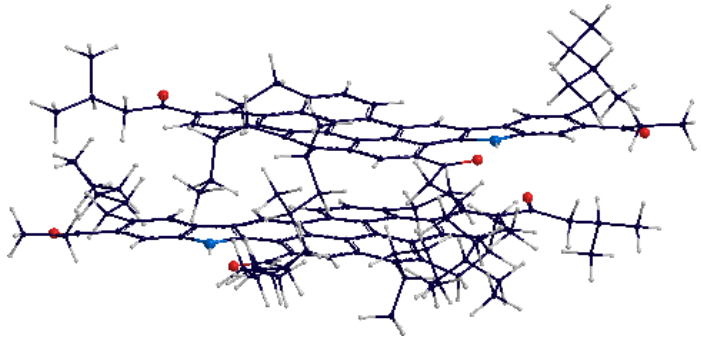
Virgin Asphaltene Dimer

E_{bind} = - 44.1 kcal/mol

d_{bind} = 3.54 A

Δd ↓

Oxidative Aging



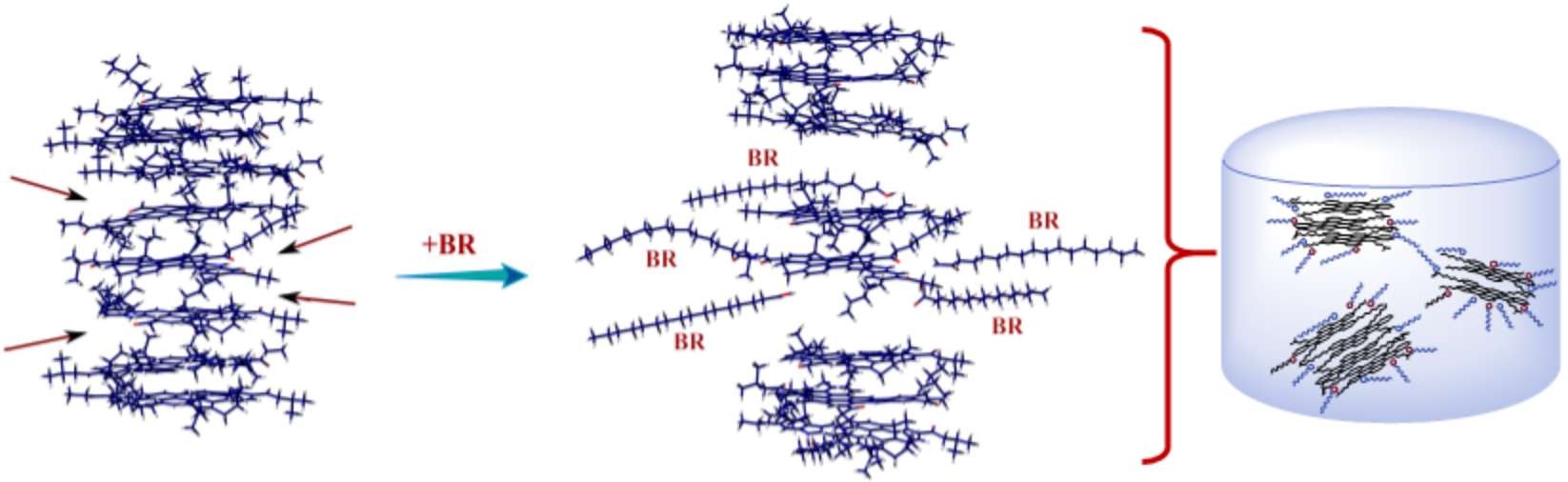
Oxidized Asphaltene Dimer

E_{bind} = - 48.8 kcal/mol

d_{bind} = 3.48 A

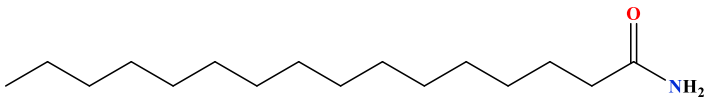
Solution 2: Rejuvenate Aged Asphalt

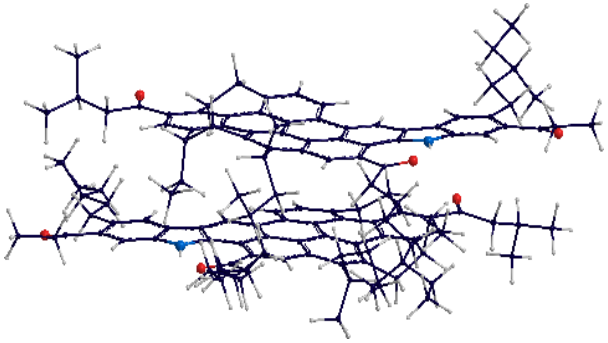
Schematic representation of BR action on the oxidized asphaltene agglomerates



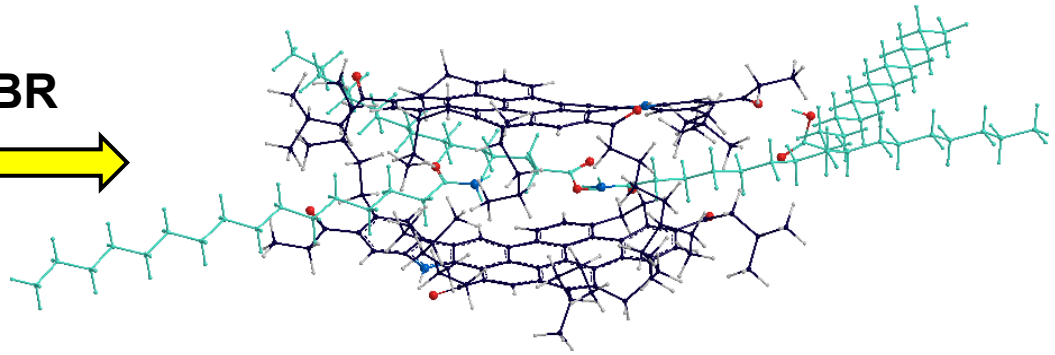
Effect of Amides on Deagglomeration

Bio-Rejuvenator: hexadecanamide





+BR



E_{bind} = -48.8 kcal/mol

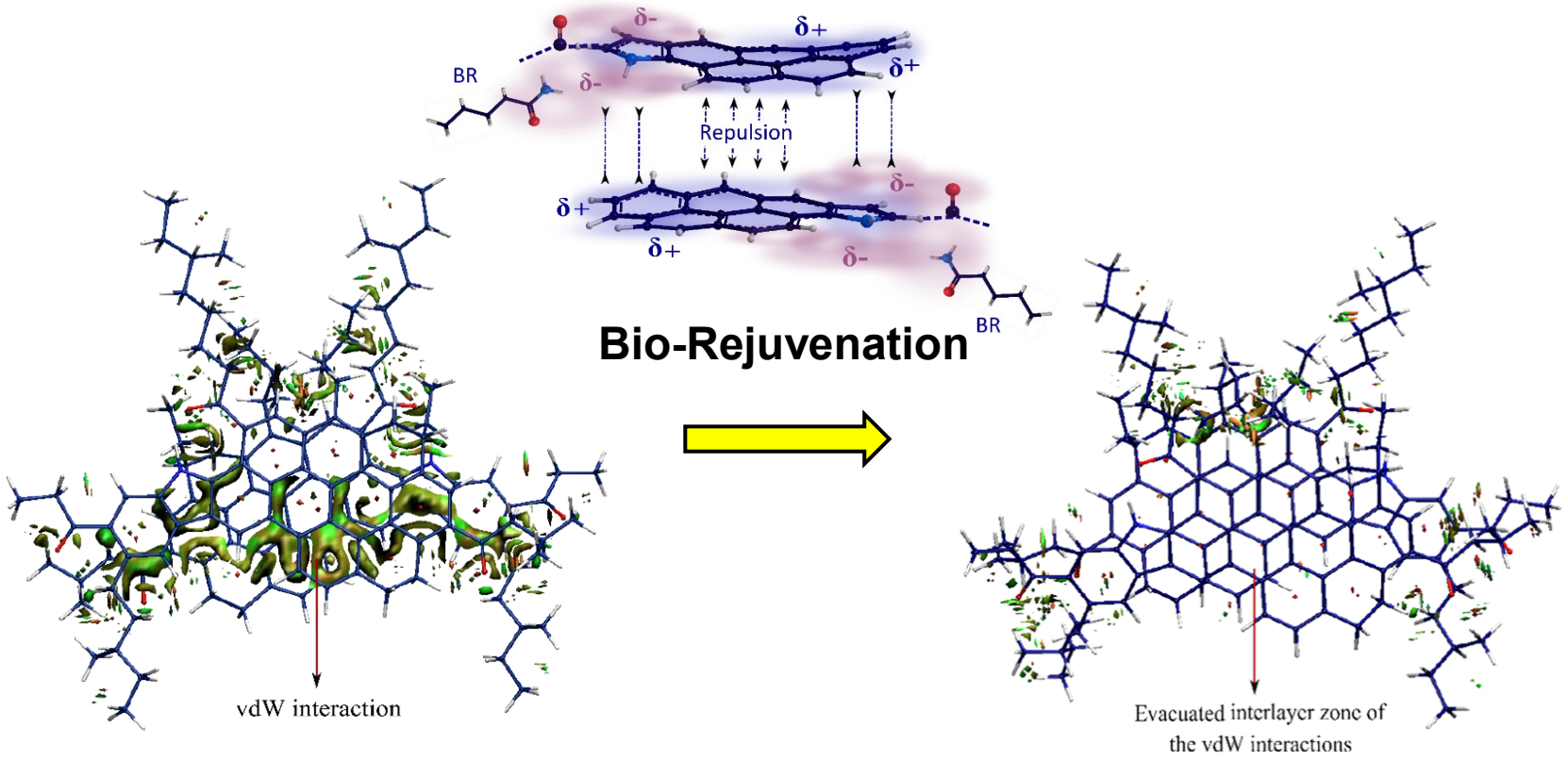
d_{bind} = 3.48 A

E_{bind} = -15.0 kcal/mol

d_{bind} = 7.17 A

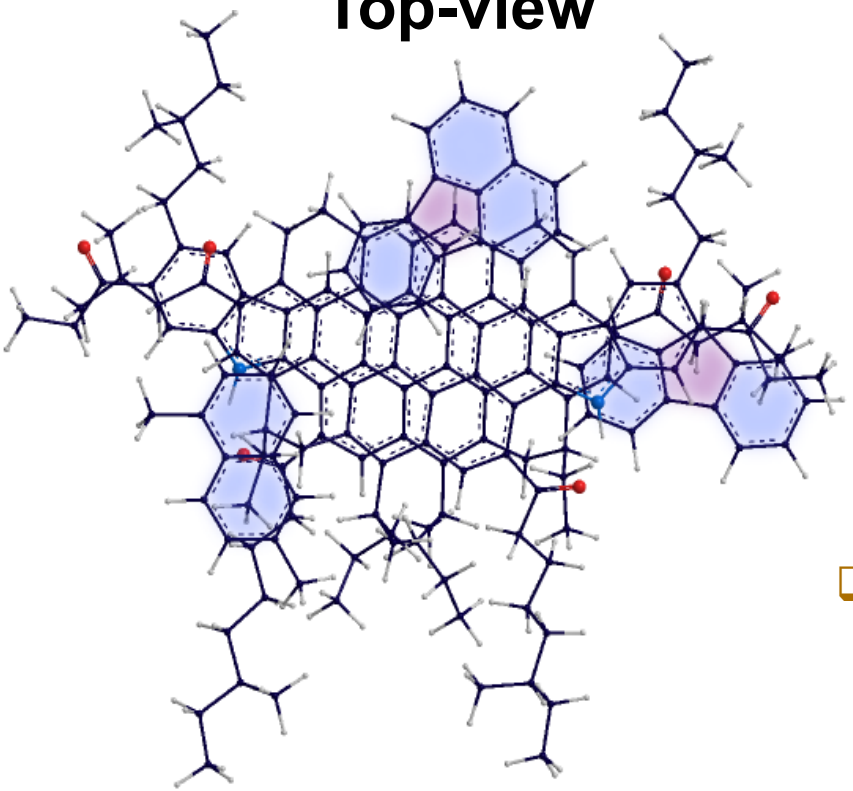
Effect of Amides on Deagglomeration

Electronic Perturbation Induced by hexadecanamide in Asphaltene Sheets

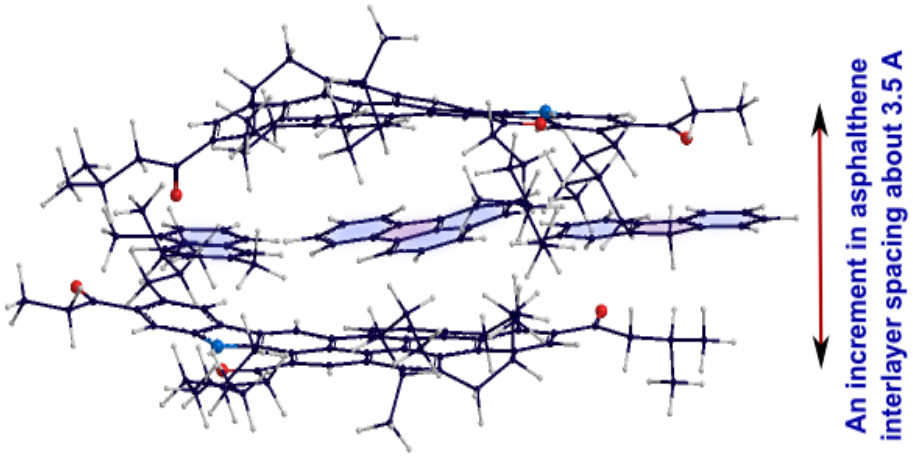


Effects of Aromatics on Deagglomeration

Top-view



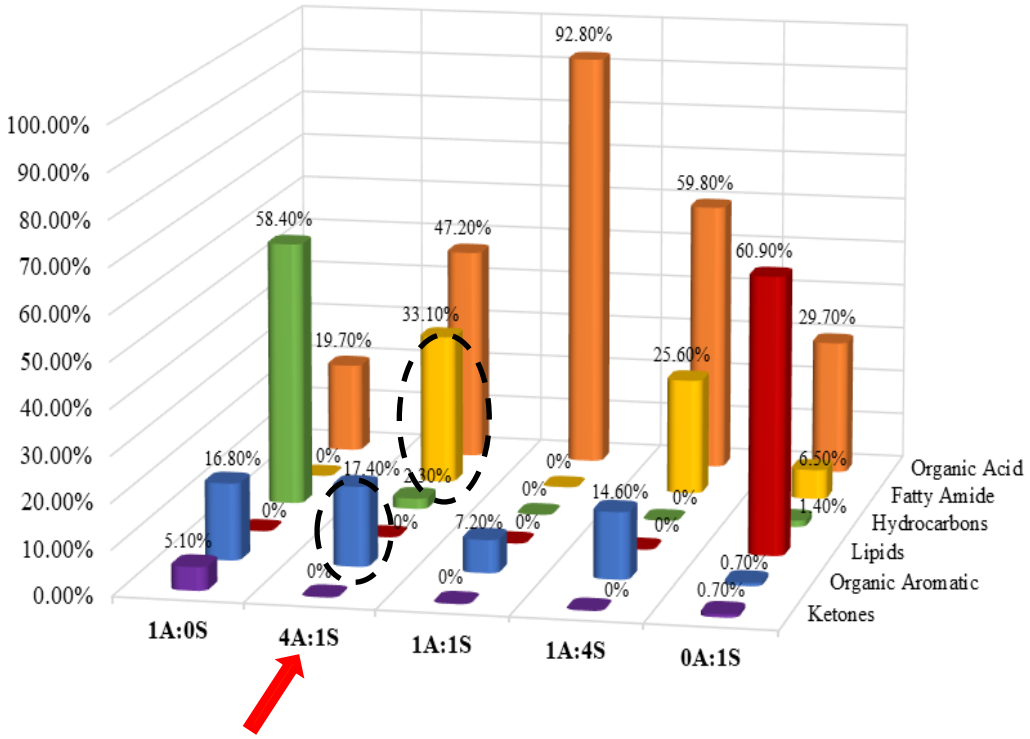
Side-view

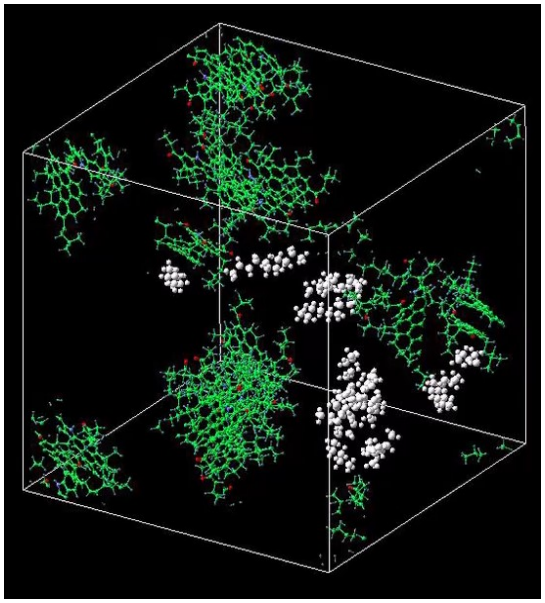


- **Weakening effect on the intermolecular interactions between asphaltenes and obvious deagglomeration**

Pahlavan, F., Sh. Hosseinnezhad, A. Samieadel, A. Hung, and E. H. Fini, 2019, Fused Aromatics To Restore Molecular Packing of Aged Bituminous Materials, *Industrial and Engineering Chemistry Research*, 58(27):11939-11953, https://doi.org/10.1021/acs.iecr.9b01397

Having a **reliable test** which measures extent of true rejuvenation, we can synthesize right rejuvenator from known and **abundant building blocks**…

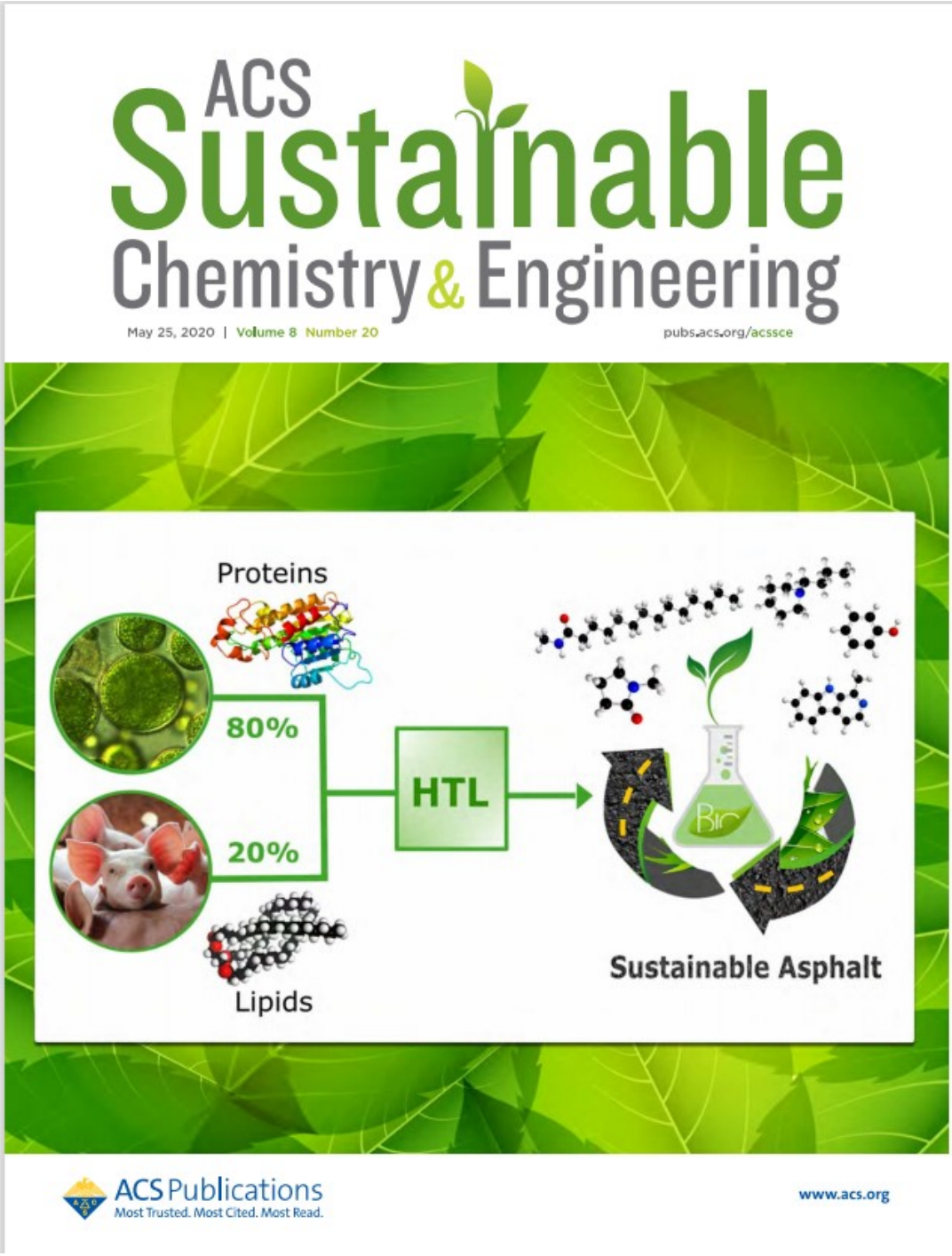




Swilgae

A patent pending technology to rejuvenate aged asphalt

Pahlavan, F., A. I. Rajib, E. H. Fini, *ACS Sustainable Chemistry & Engineering*, https://doi.org/10.1021/acssuschemeng.0c01100



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