

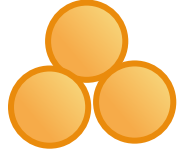
Beyond NMP: A New Framework for Non-Toxic Solvents in Battery Recycling

Muntasir Shahabuddin, Gabriel Salierno, Gregory
Morose, Michael Timko

Spring TUR Conference
April 8th, 2026

Battery manufacturing is complex to scale – and further constrained by toxicity

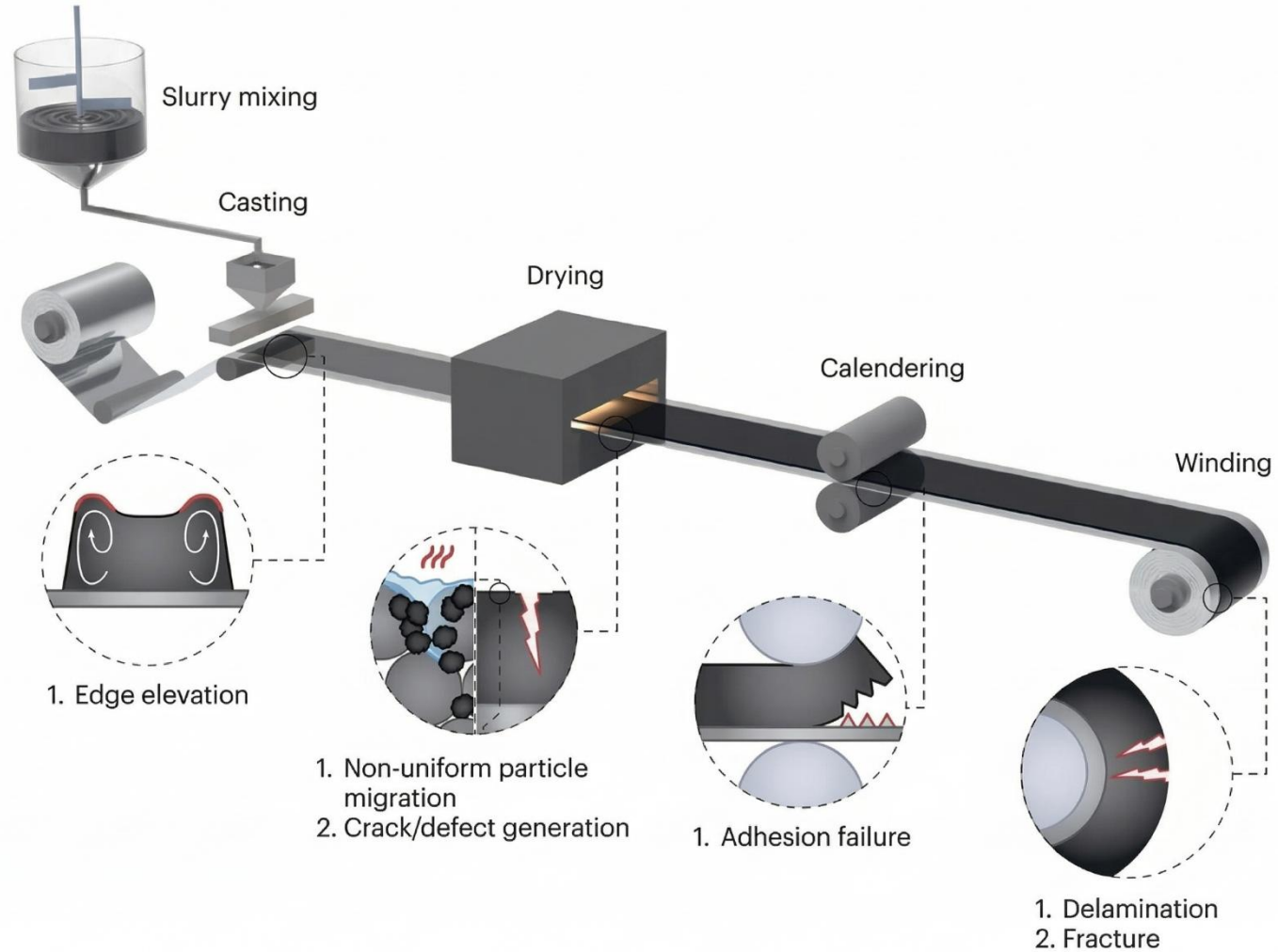
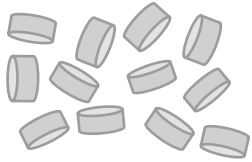
Li-oxide



Carbon

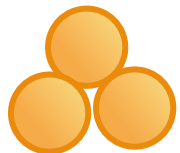


PVDF



Materials in lithium-ion batteries must be adhered together with a polymer binder

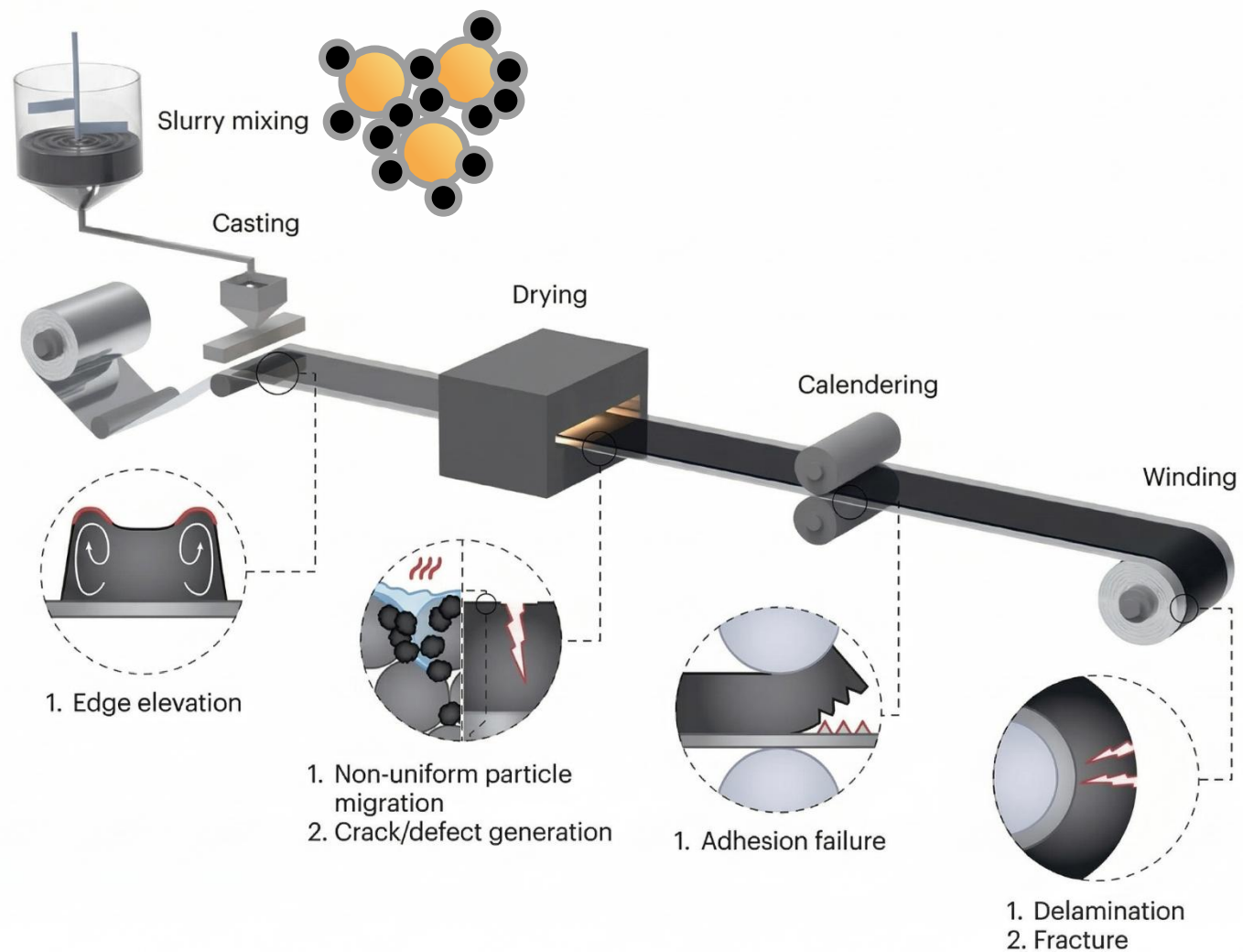
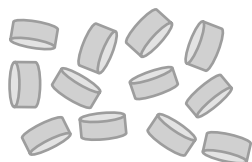
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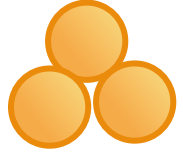


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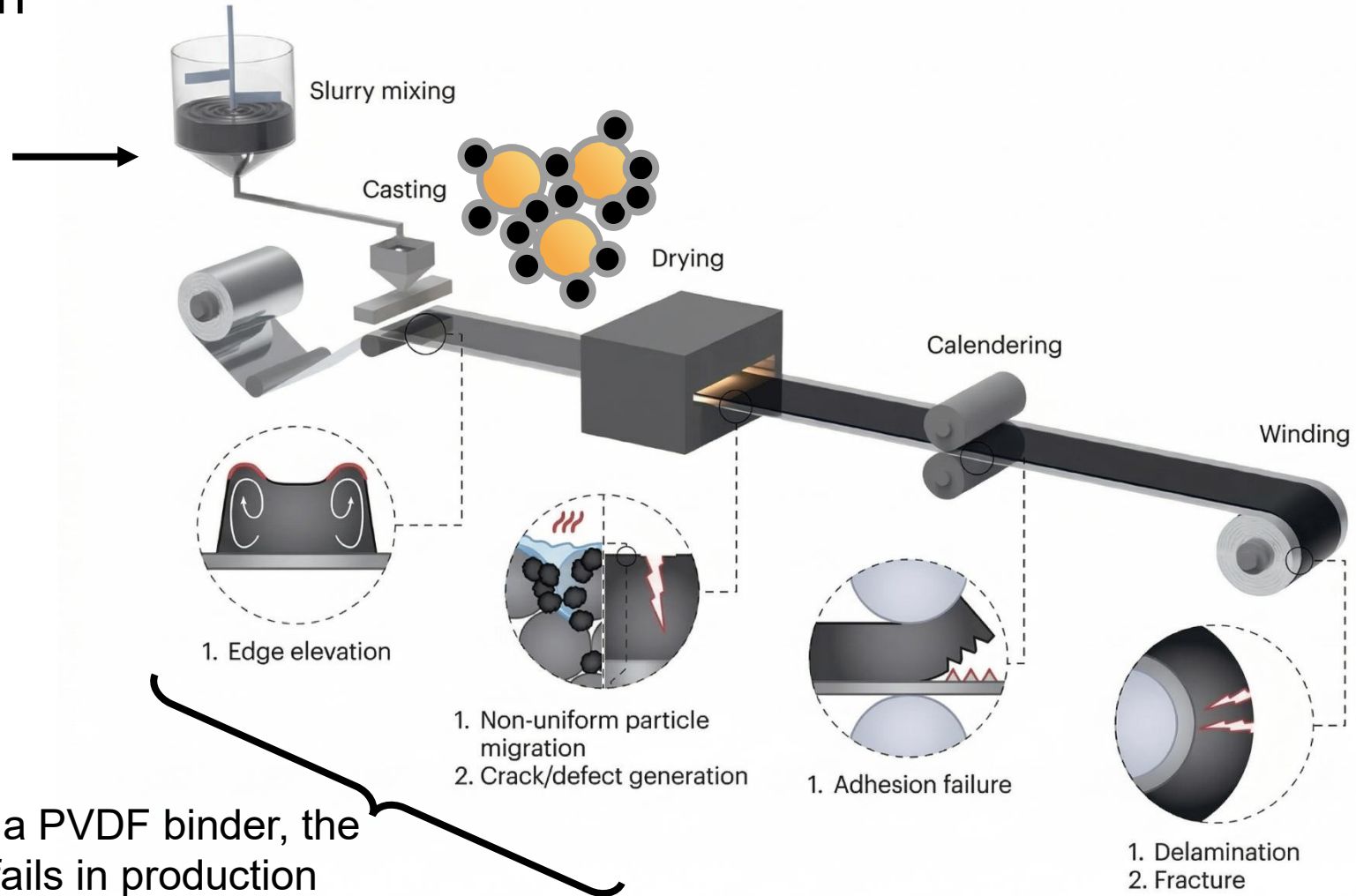
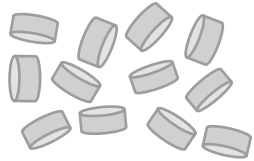
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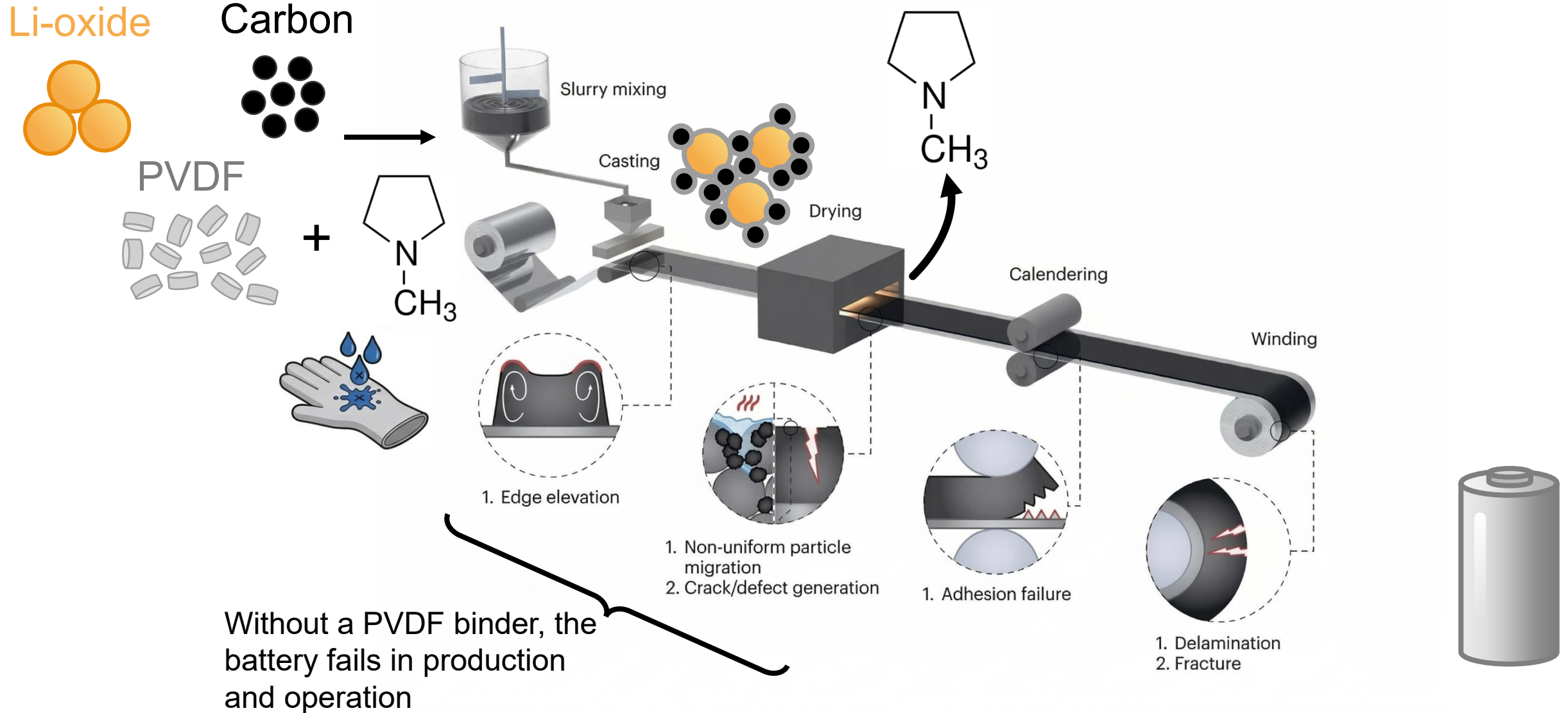


PVDF



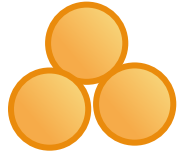
Without a PVDF binder, the battery fails in production and operation

Dissolving PVDF requires a toxic solvent – N-methyl-2-pyrrolidone (NMP)

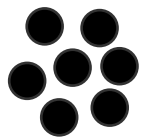


Most exposure risk peaks when mixing and dissolving PVDF and drying off solvent

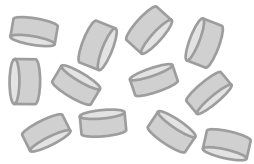
Li-oxide



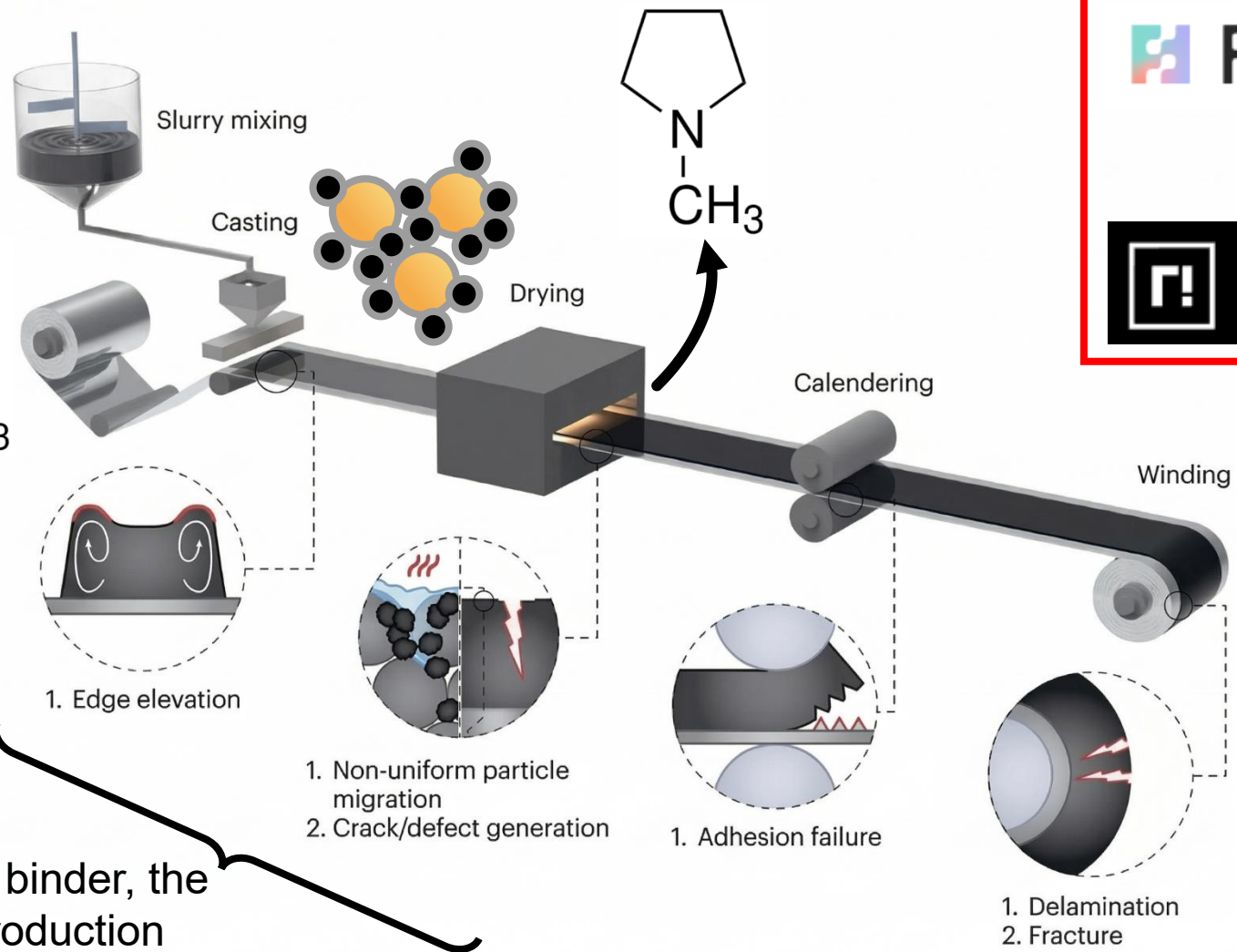
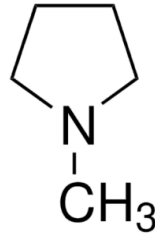
Carbon



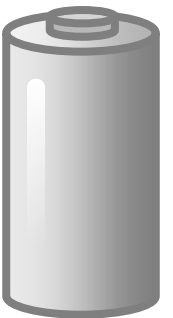
PVDF



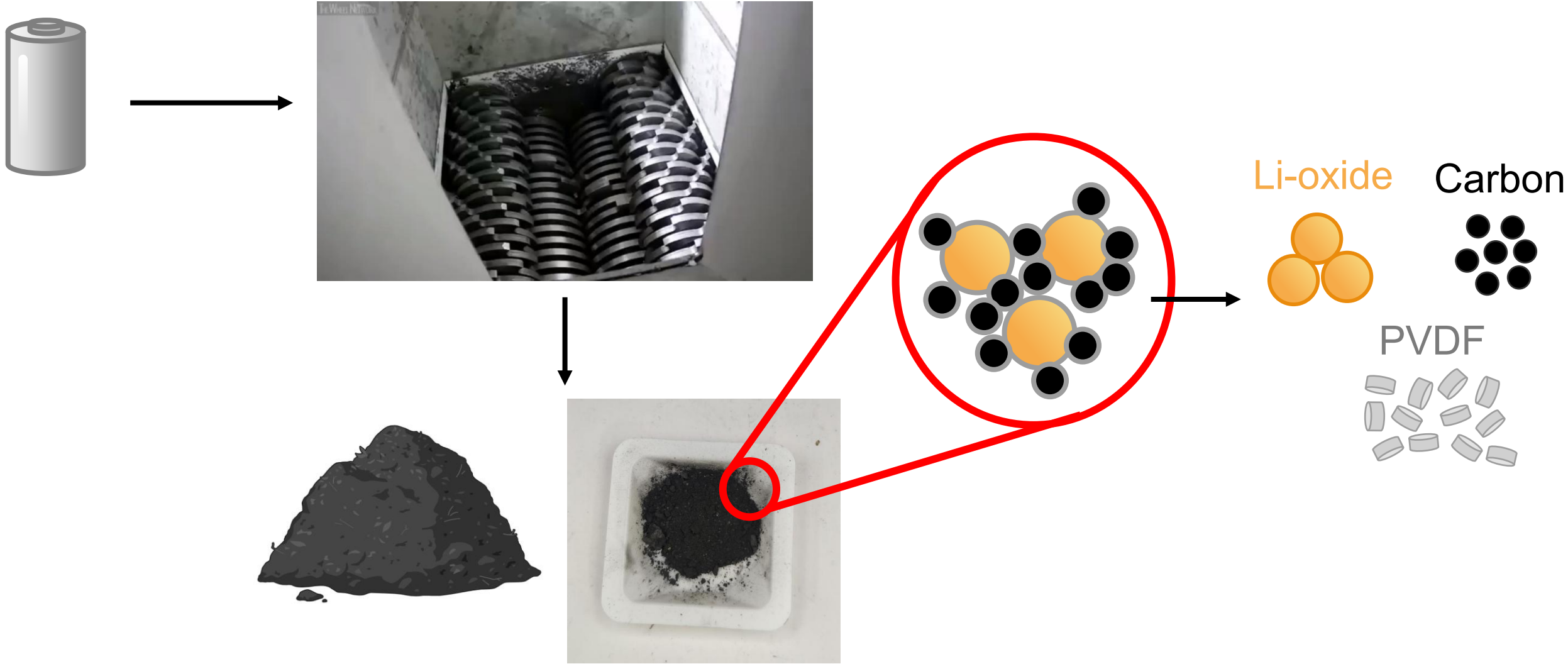
+



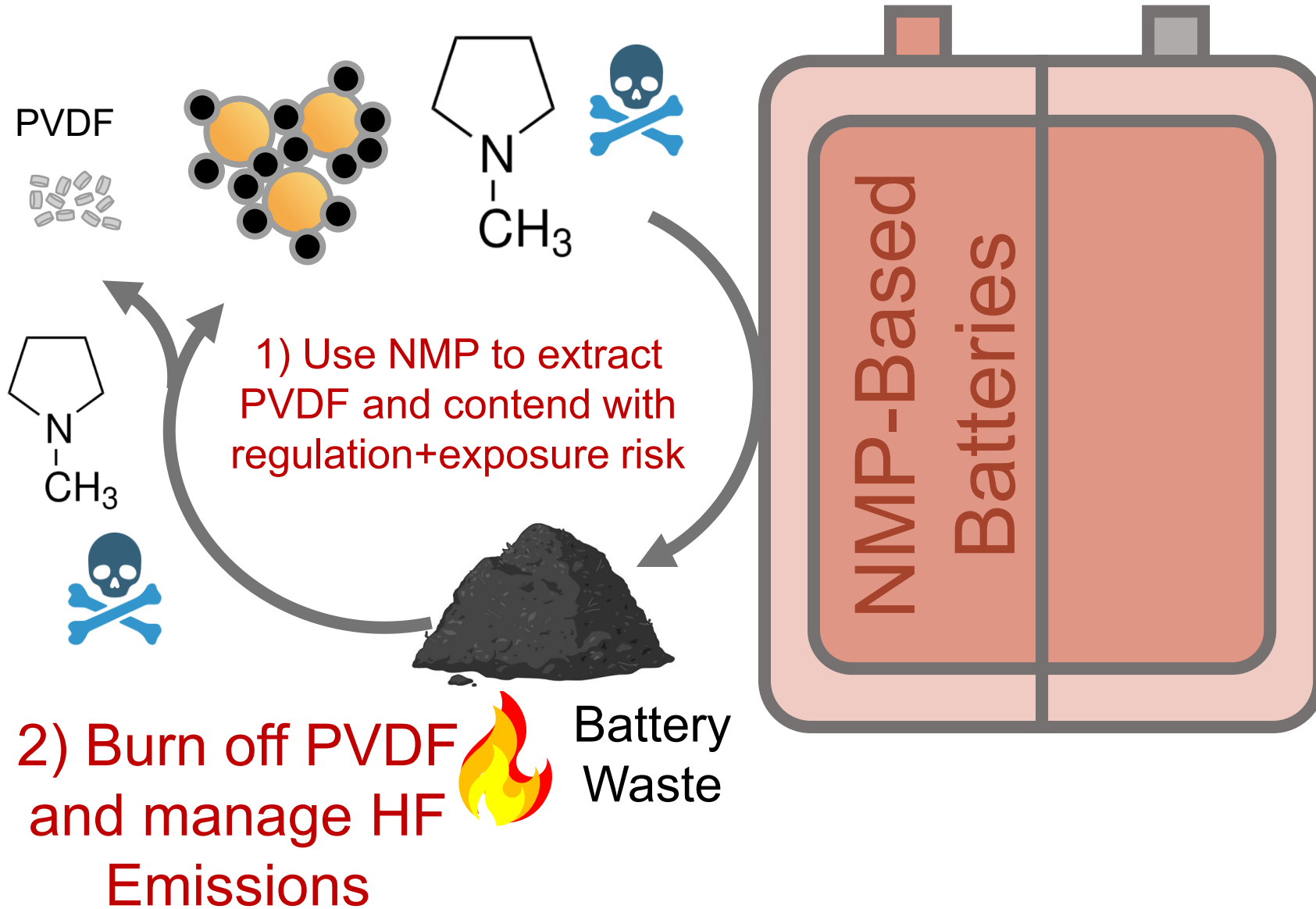
Without a PVDF binder, the battery fails in production and operation



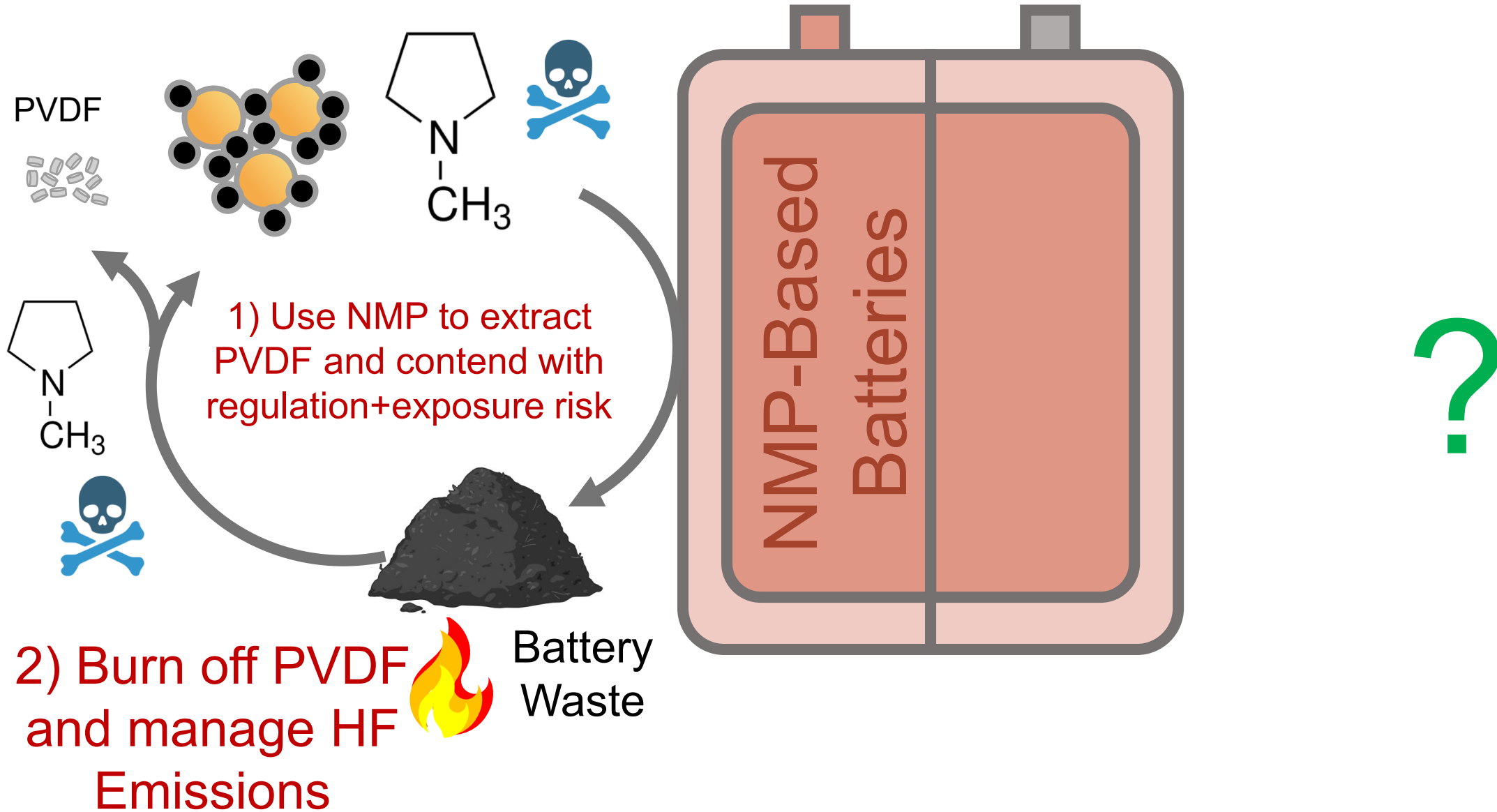
At end-of-life, mechanical shredding leaves PVDF residue that impedes material recovery



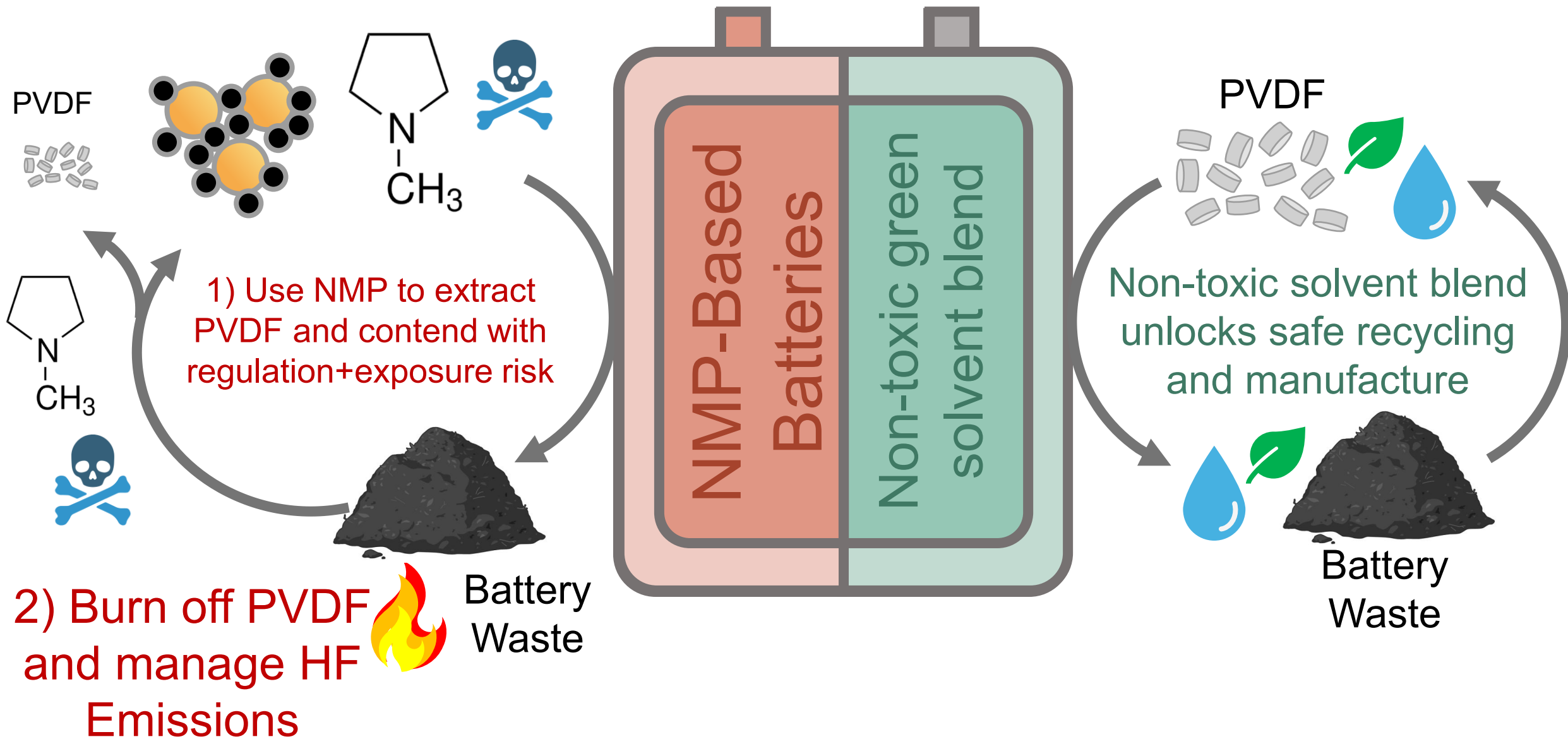
Li-ion battery recyclers are typically left with two options:



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Option 3: Advance science and identify a performant, non-toxic alternative to NMP



TURI & WPI: Designing drop-in non-toxic NMP substitutes

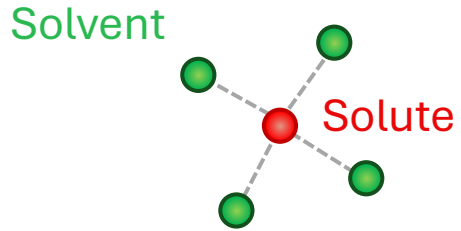
Filter Solvents by
Solvation Performance

**How can we screen
through thousands
of chemicals and
know which could
potentially dissolve
PVDF?**

Downselect by Toxicity

Cost < NMP

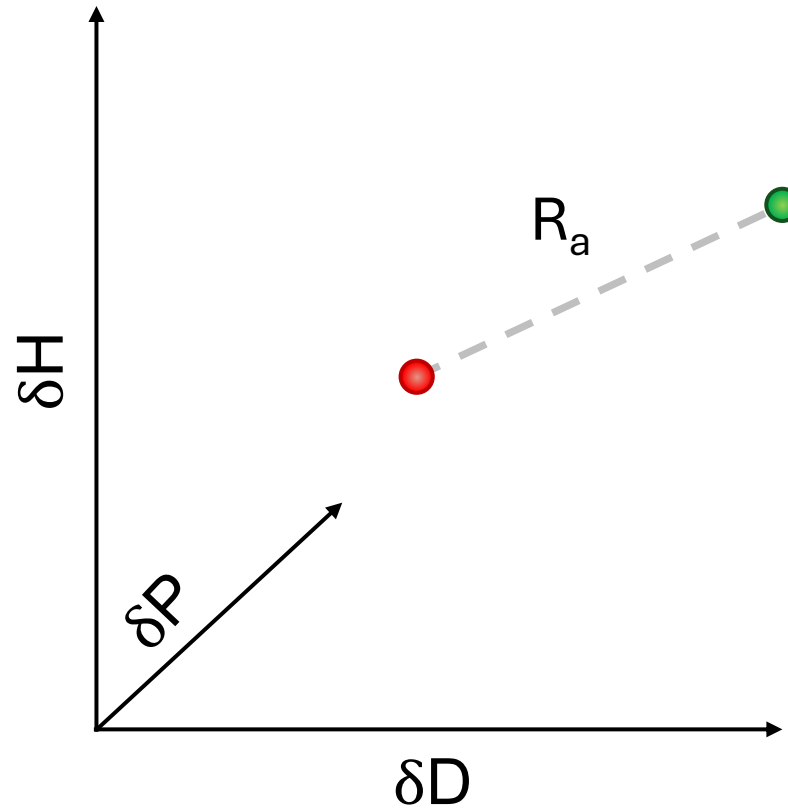
Current efforts use Hansen parameters to quantify solvation capability



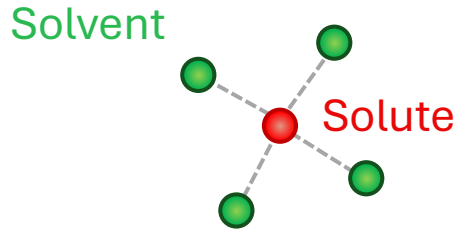
δD = Dispersion

δP = Polar

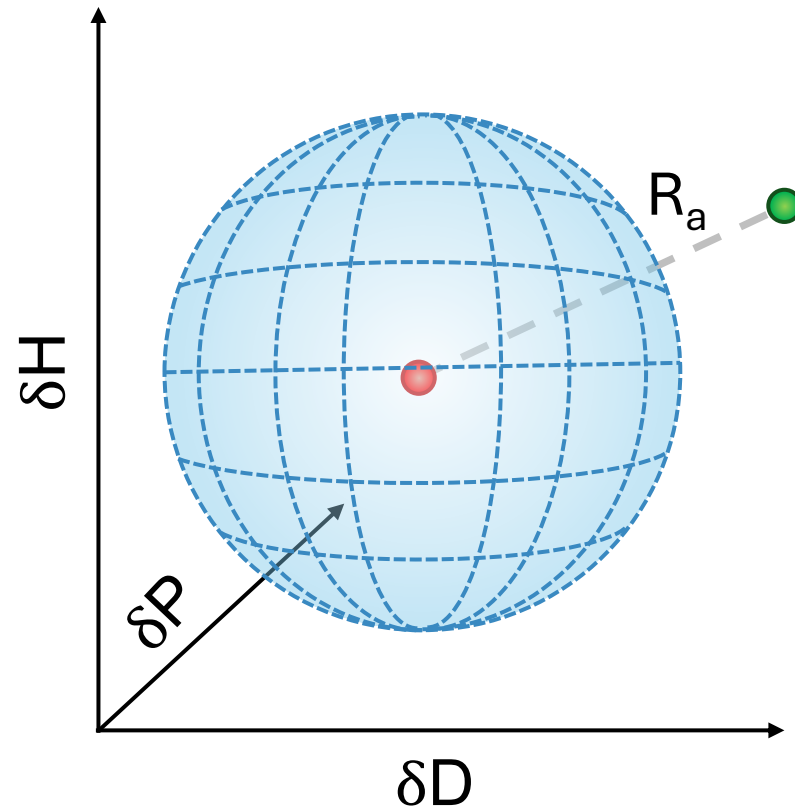
δH = Hydrogen
Bonding



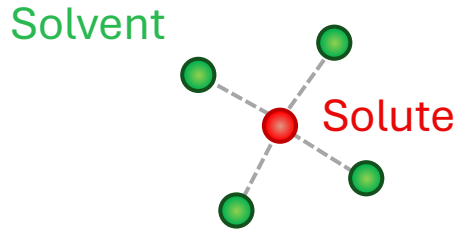
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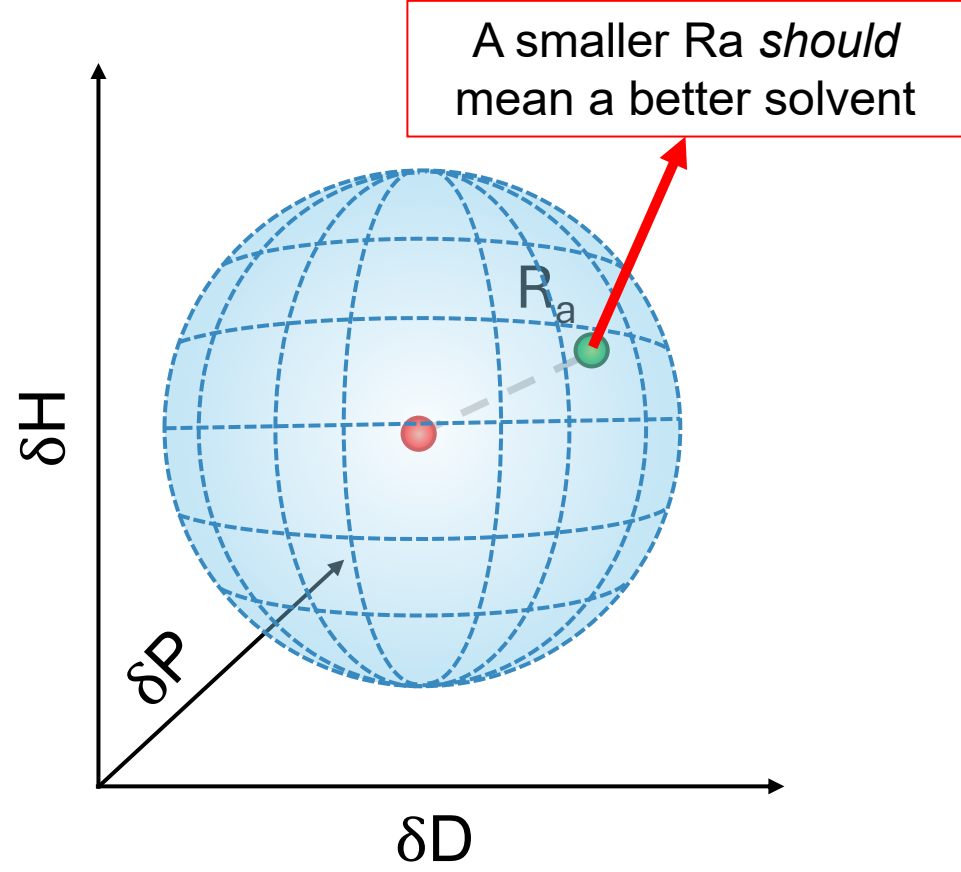
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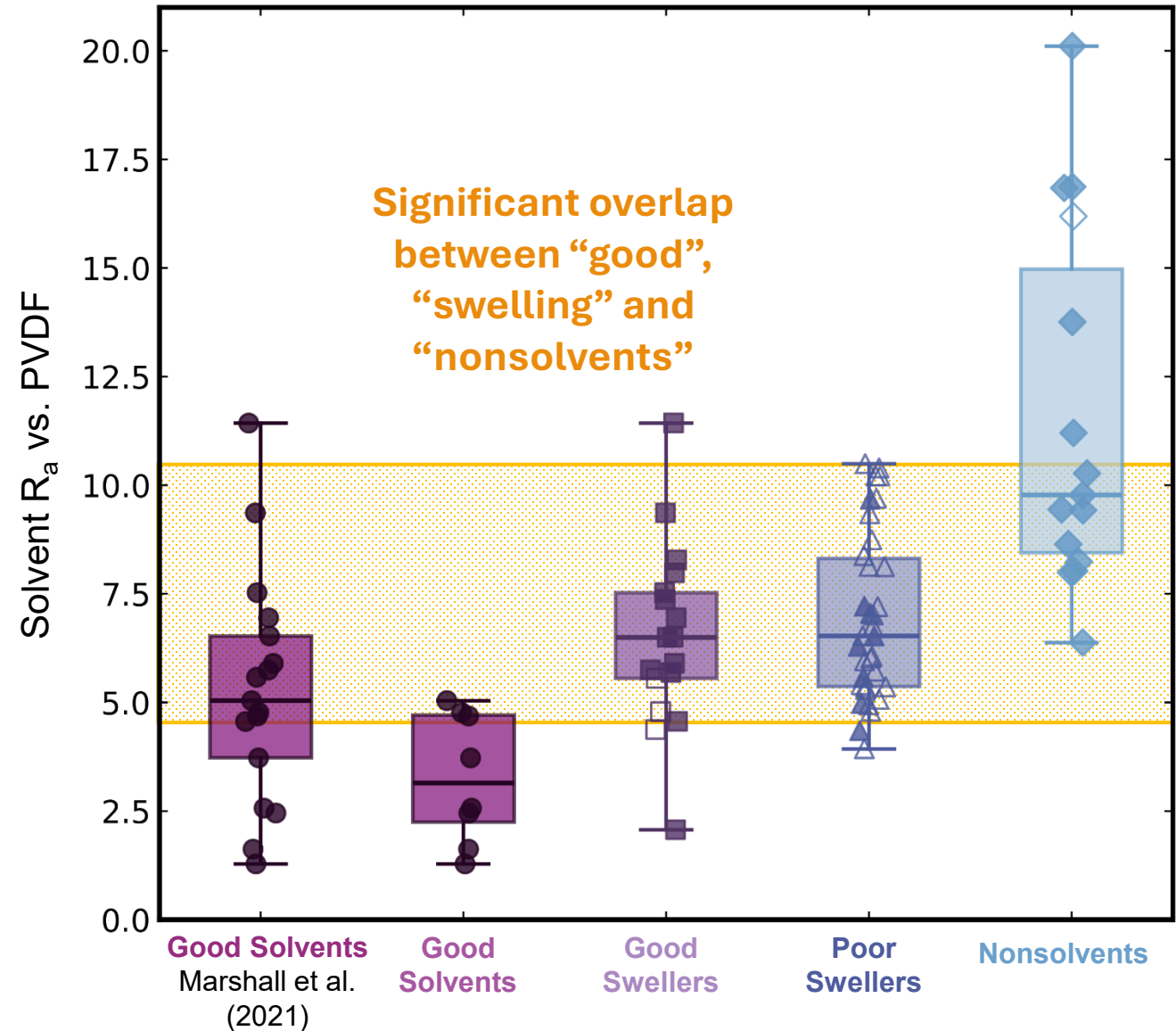
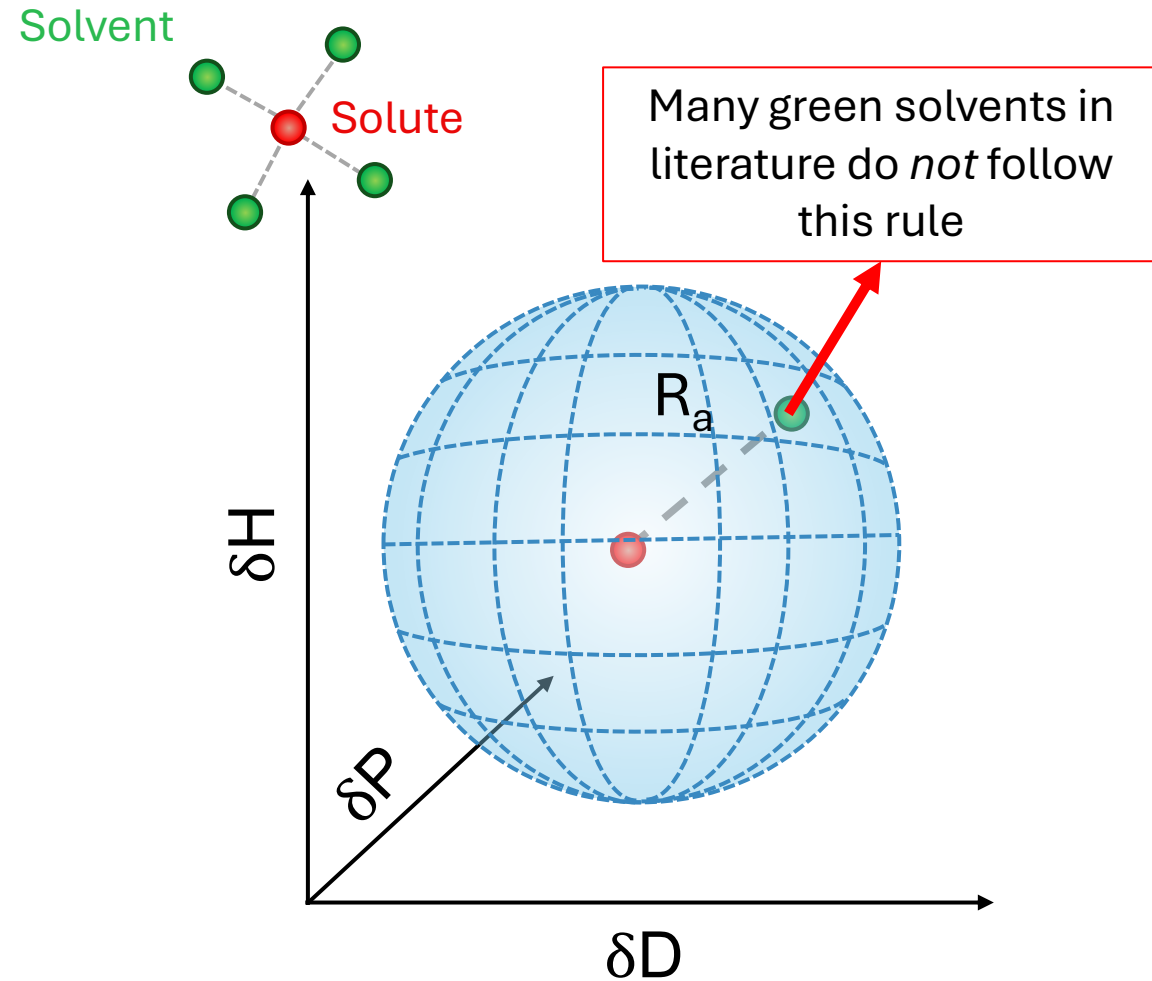
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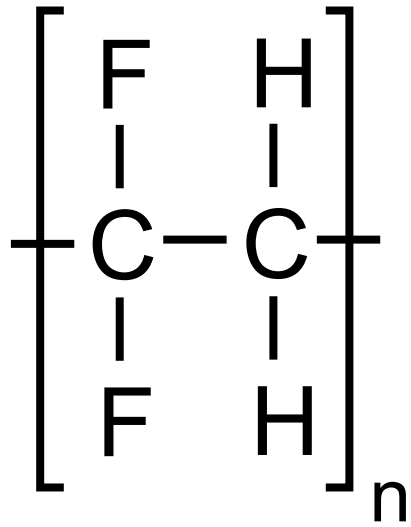
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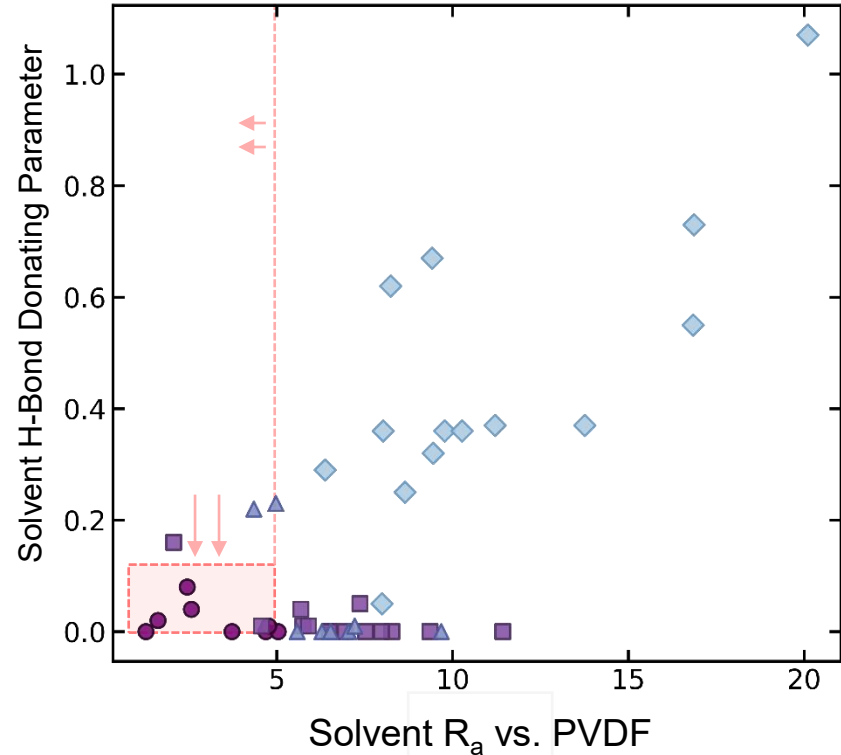


The missing link: *directionality* of hydrogen bonding

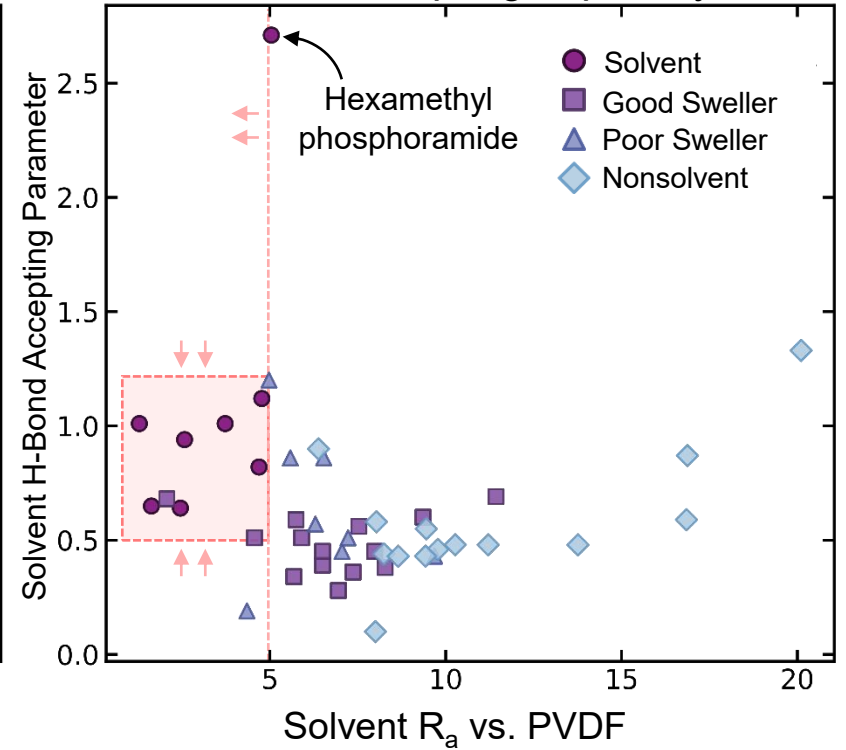


Good PVDF solvents must *also* have

Low hydrogen bond donating capability

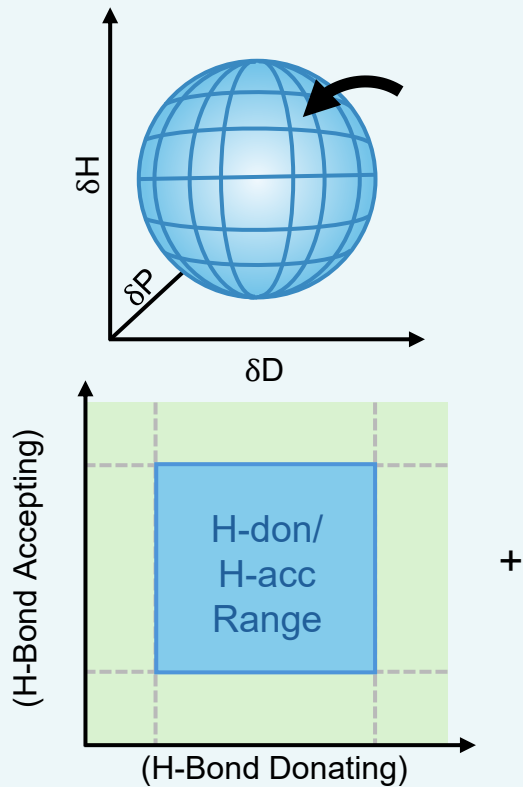


A specific range of hydrogen bond accepting capability



TURI & WPI: Designing drop-in non-toxic NMP substitutes

Filter Solvents by Solvation Performance

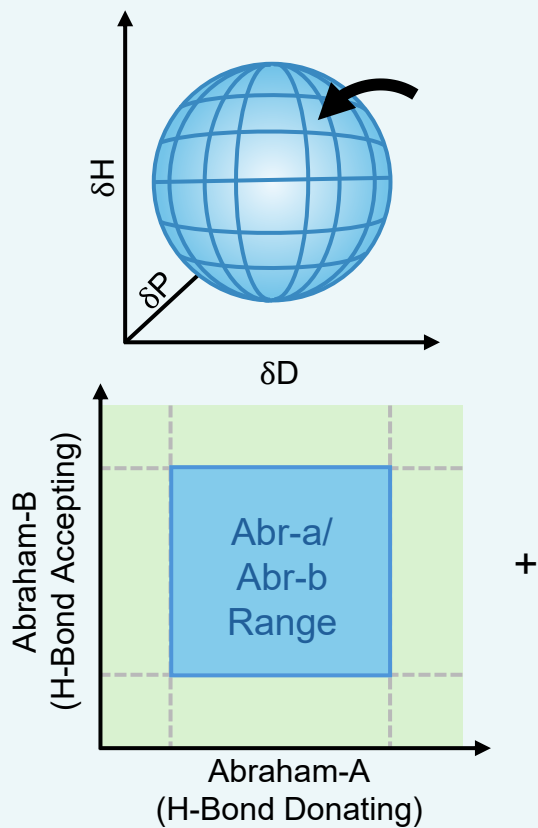


Downselect by Toxicity

Cost < NMP

TURI & WPI: Designing drop-in non-toxic NMP substitutes

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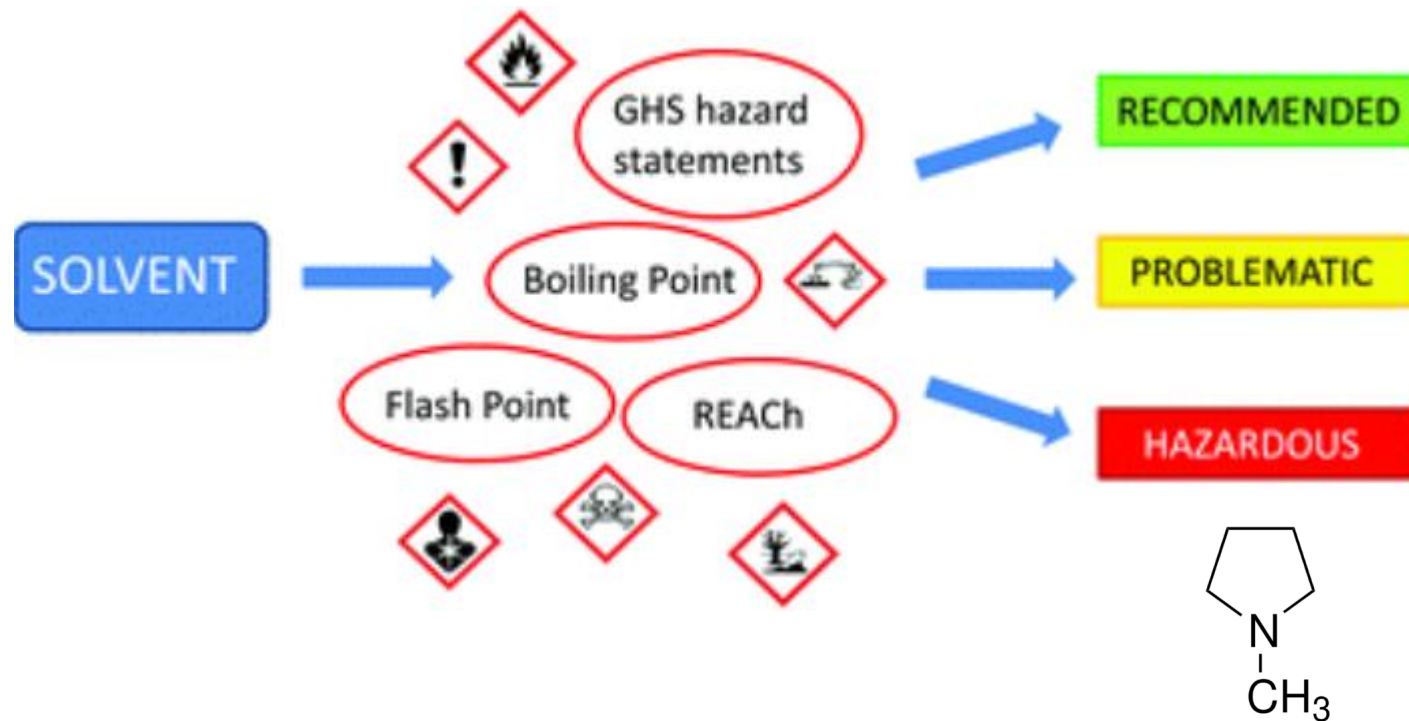
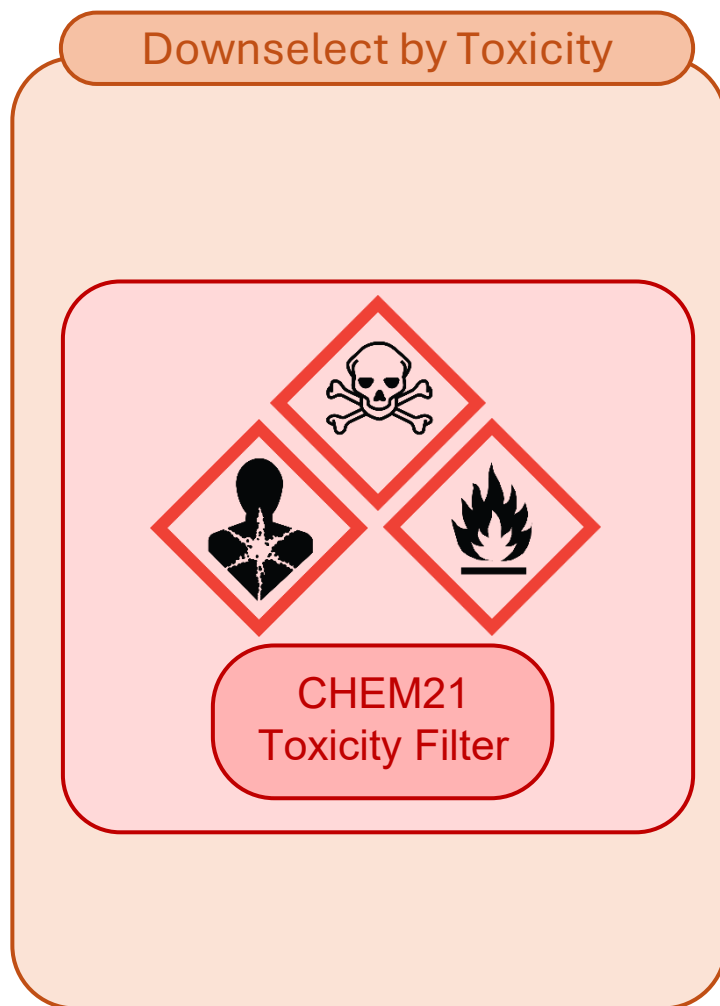
Downselect by Toxicity



CHEM21
Toxicity Filter

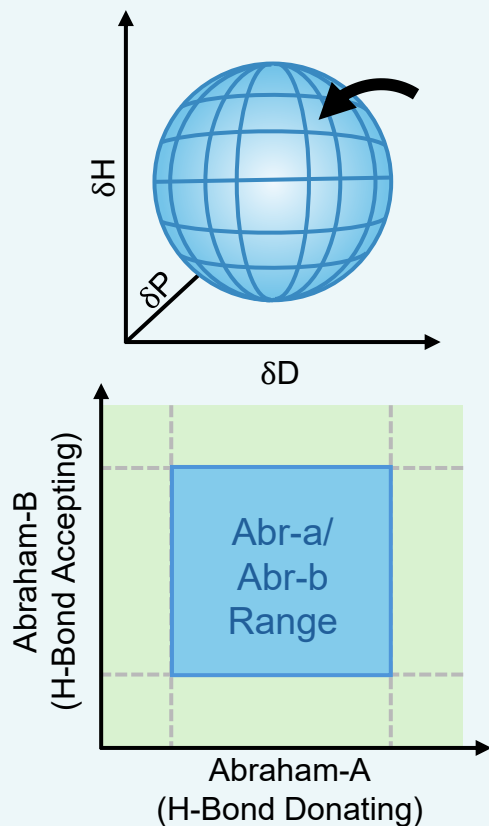
Cost < NMP

Replacement solvents must be significantly less hazardous than NMP



TURI & WPI: Designing drop-in non-toxic NMP substitutes

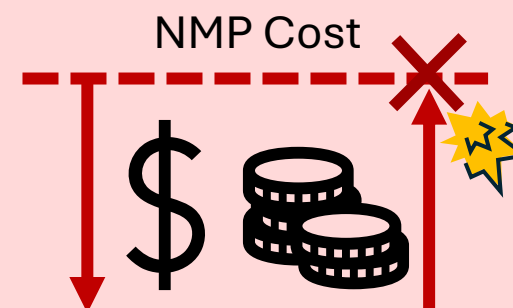
Filter Solvents by Solvation Performance



Downselect by Toxicity

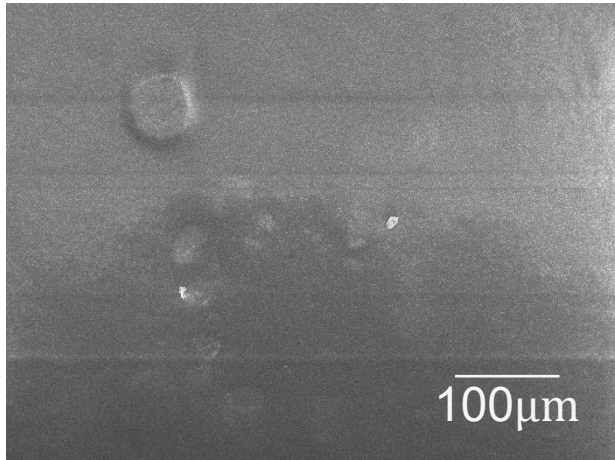


Cost < NMP

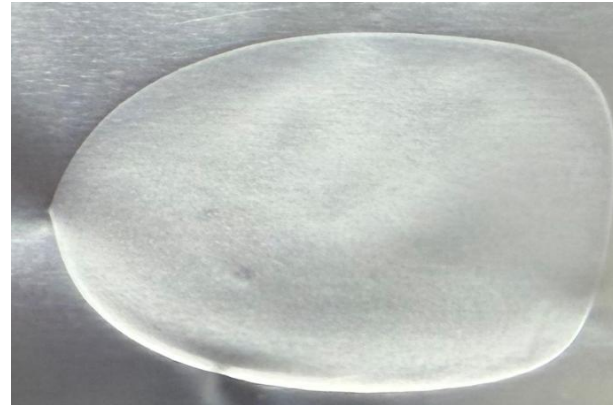
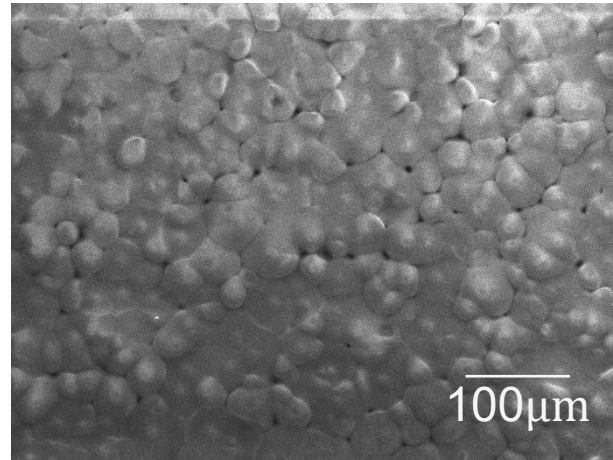


Identifying a non-toxic solvent alternative to NMP

New Solvent-based
PVDF Coating

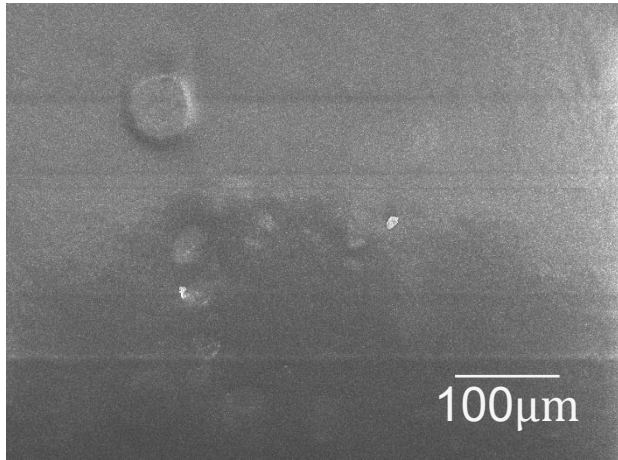


NMP-Based
PVDF Coating

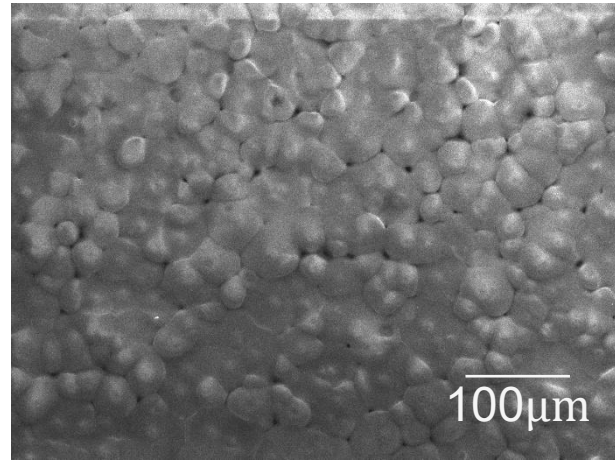


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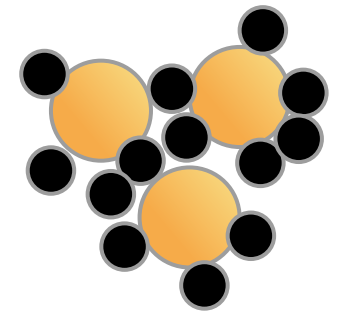
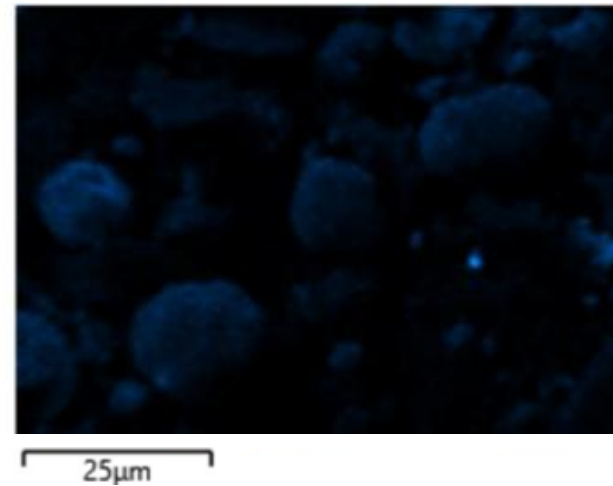
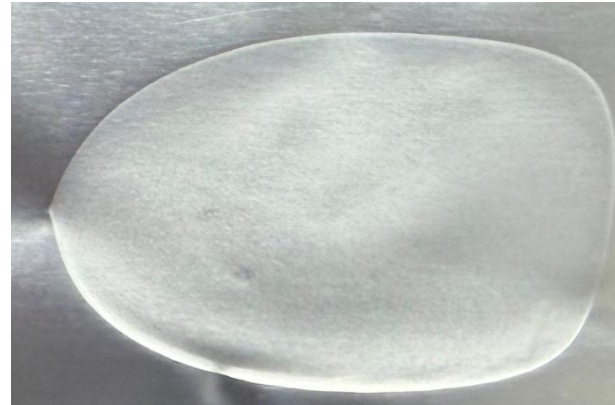
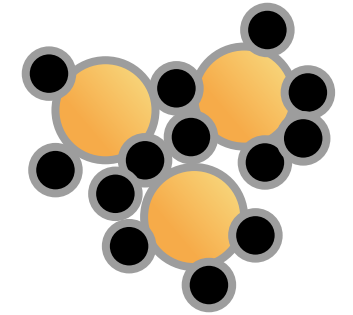
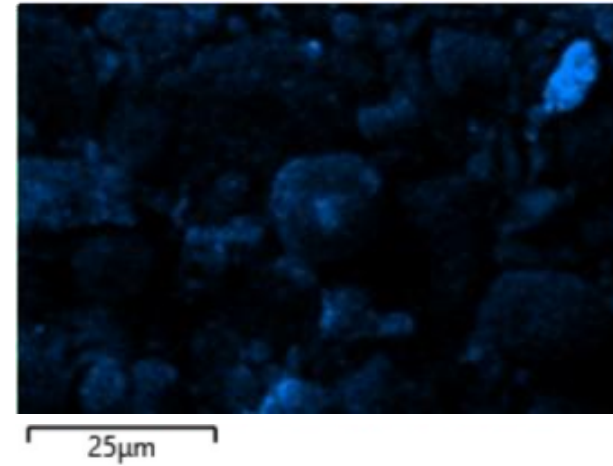
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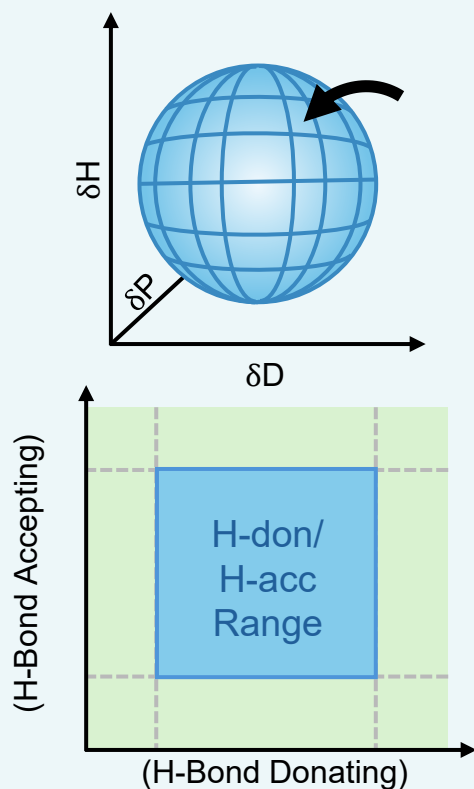


New Solvent
Black Mass
Extraction



TURI & WPI: Designing a framework for drop-in non-toxic NMP substitutes

Filter Solvents by Solvation Performance

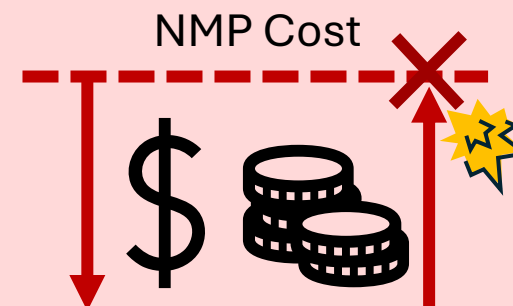


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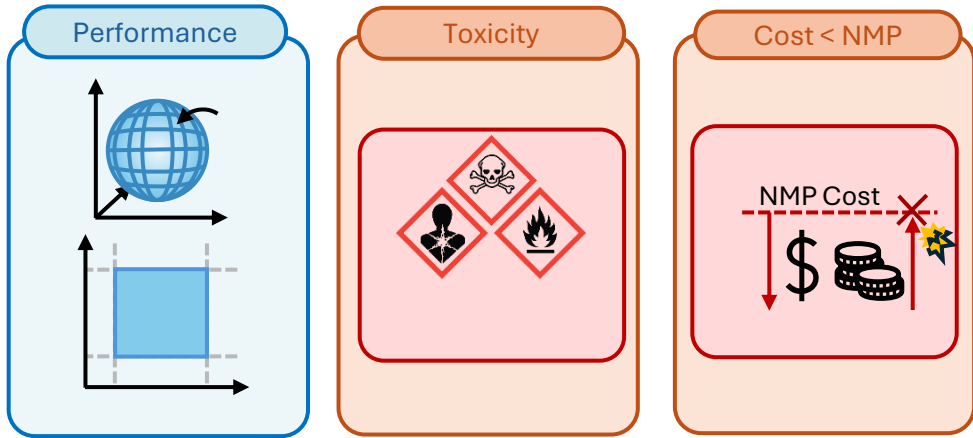


CHEM21
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WPI