Incorporating New Approach Methodologies in Risk Assessments

EMAP 514: Introduction to Environmental Health Risk Assessment and Management

Environmental Metrology and Policy Program

GEORGETOWN UNIVERSITY

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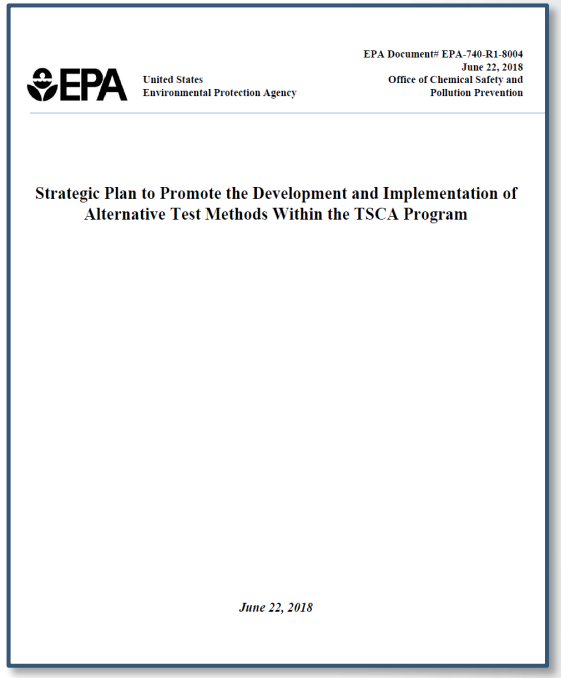
The views presented are those of the author and do not necessarily reflect the views of the US EPA.

Definition(s) of New Approach Methods (NAMs)

- Commonly defined to include *in silico* approaches, *in chemico* and *in vitro* assays, as well as the inclusion of information from the exposure of chemicals in the context of hazard assessment.

- Recently defined in the EPA's TSCA Alternative Toxicity Strategy as:
  - a broadly descriptive reference to any technology, methodology, approach, or combination thereof that can be used to provide information on chemical hazard and risk assessment that avoids the use of intact animals.


EPA Document# EPA-740-R1-8004
June 22, 2018
Office of Chemical Safety and Pollution Prevention

EPA United States Environmental Protection Agency

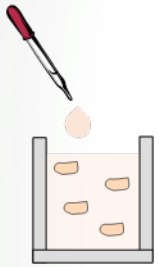
Strategic Plan to Promote the Development and Implementation of Alternative Test Methods Within the TSCA Program

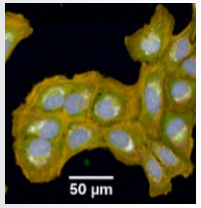
June 22, 2018

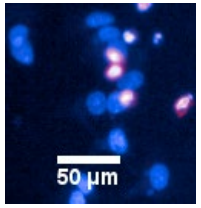
https://echa.europa.eu/documents/10162/22816069/scientific_ws_proceedings_en.pdf

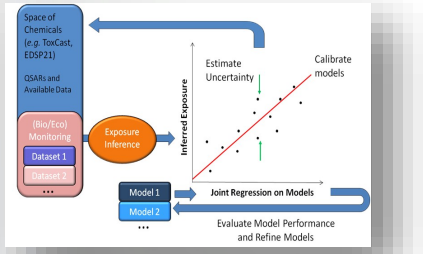
https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/alternative-test-methods-and-strategies-reduce

Examples of NAMs

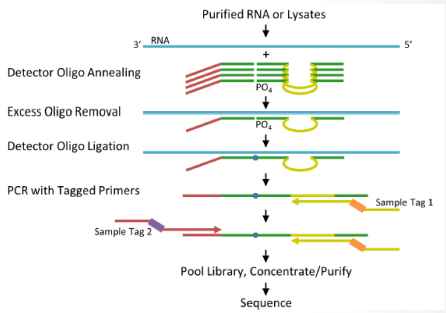


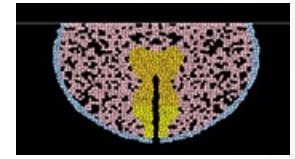


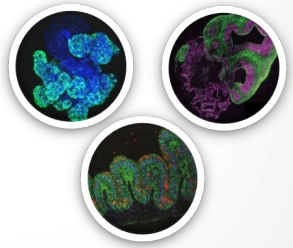




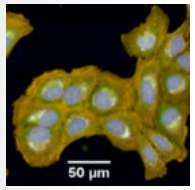
- In silico (e.g. QSAR and Read-across)
  - Estimate effects and doses
  - Consensus exposure modeling
- In vitro assays
  - Broad / screening (transcriptomics, cell painting)
  - Targeted (receptors, enzymes)
  - In vitro PODs, modes / mechanisms of action
- In vitro Toxicokinetics
  - Allow conversion of an in vitro POD to in vivo (IVIVE)
- High-throughput Exposure Measurements
  - To fill data gaps in monitoring data
- Computer models
  - Hazard models to integrate multiple in silico and in vitro data streams
  - Exposure models to increase information on different pathways of exposure

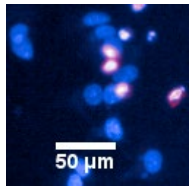


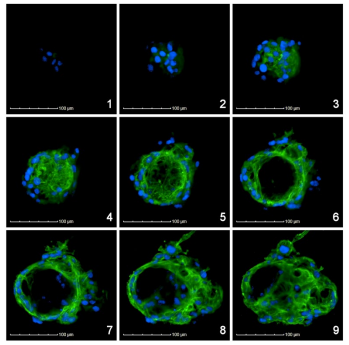


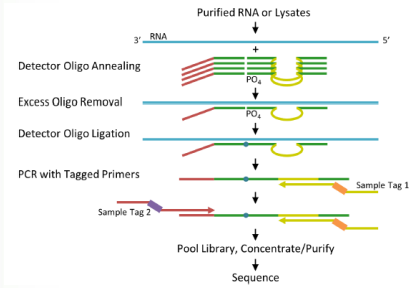


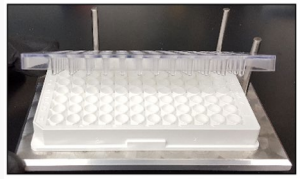
Potential Challenges with New Approach Methods

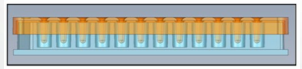


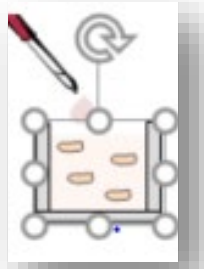


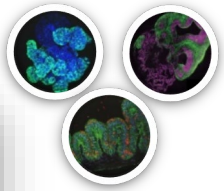






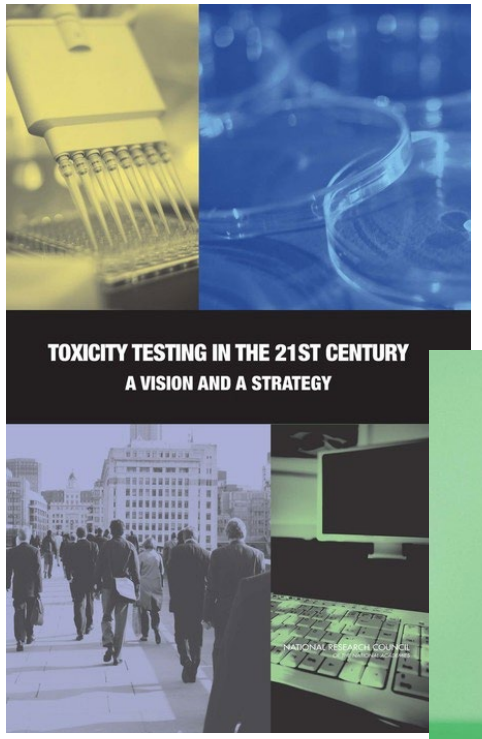


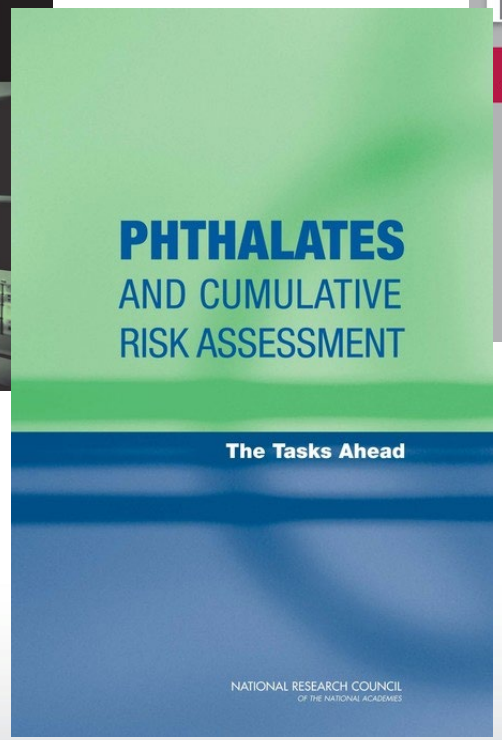


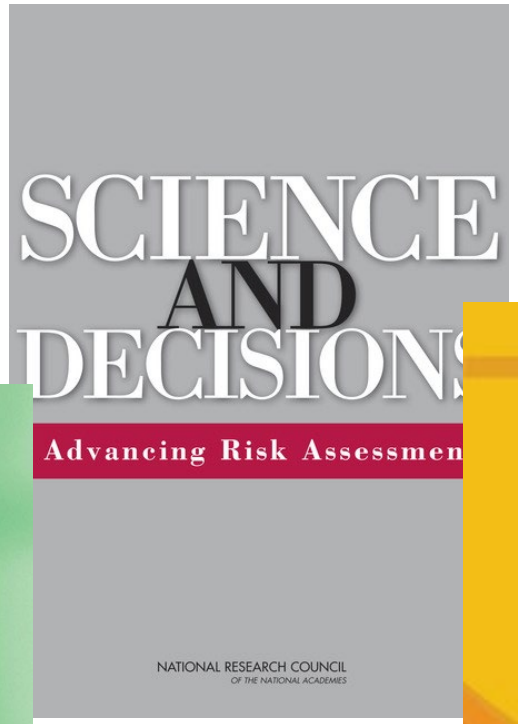


- Incomplete coverage of important pathways (i.e., biological space)
- Limited higher order biological interactions (i.e., cell-cell, tissue, and organ-level)
- Limited or lack of relevant metabolism
- Addressing uncertainties

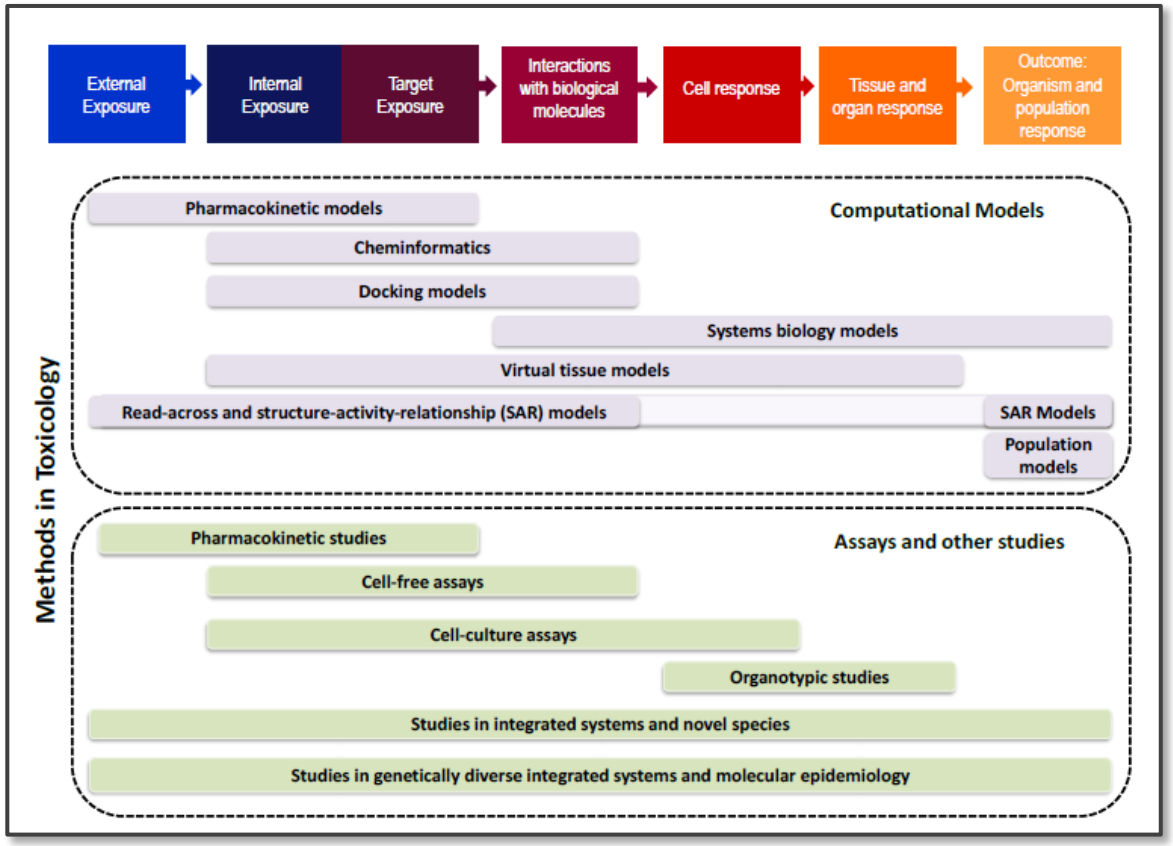
Advancing Risk Assessment







Toxicology Moving to Embrace 21st Century Methods

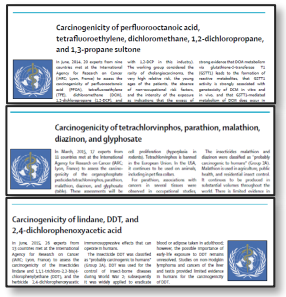


https://www.nap.edu/catalog/24635/using-21st-century-science-to-improve-risk-related-evaluations

Where can NAMs "fit" in Risk Assessment?

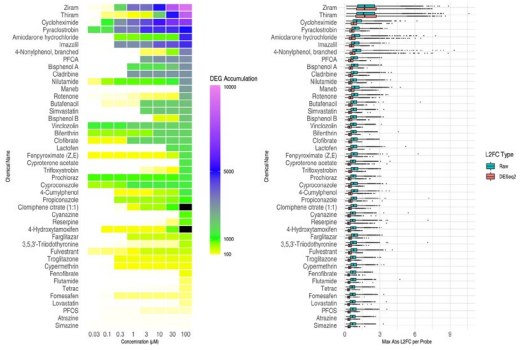
- Hazard characterization
- Dose-Response
- Exposure assessment

Provide Mechanistic Support for Hazard ID



IARC Monographs
110, 112, 113

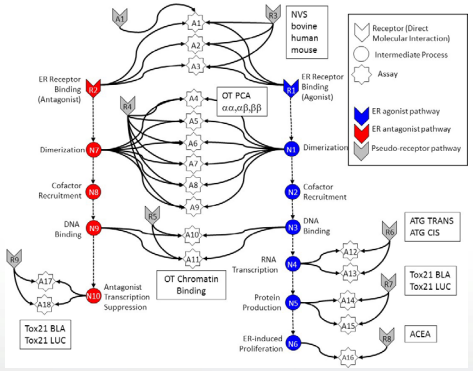
Tiered testing with High-throughput screening



Harrill et al 2021

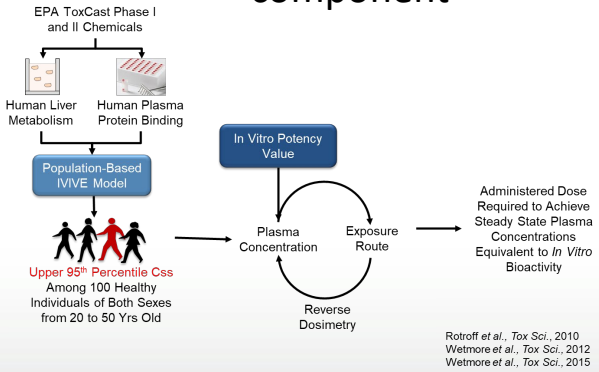
…and more!

Prioritization of Chemicals for Further Testing



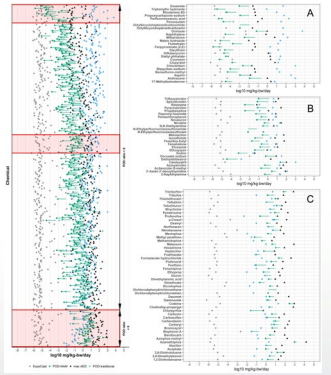
Judson et al., 2015

High-throughput toxicokinetic component



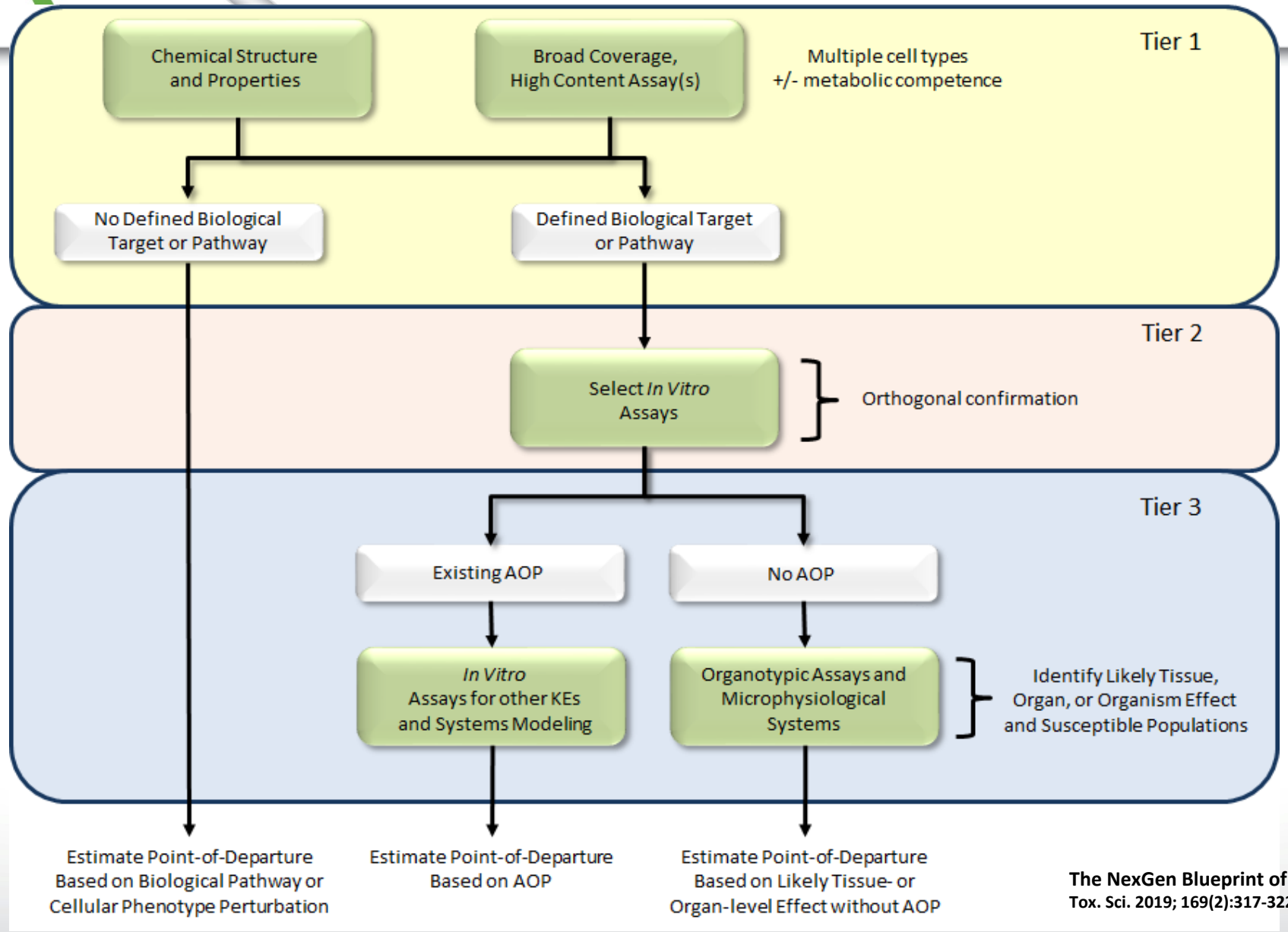
Rotroff *et al.*, *Tox Sci.*, 2010
Wetmore *et al.*, *Tox Sci.*, 2012
Wetmore *et al.*, *Tox Sci.*, 2015

In vitro point-of-departure development from NAMs



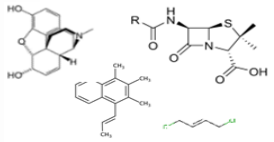
Paul Friedman et al, 2020

Tiered Hazard Evaluation Approach

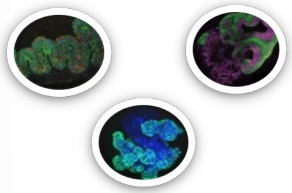


The NexGen Blueprint of CompTox at USEPA
Tox. Sci. 2019; 169(2):317-322

Incorporating High-Content Technologies to Increase Biological Coverage: Human Hazard

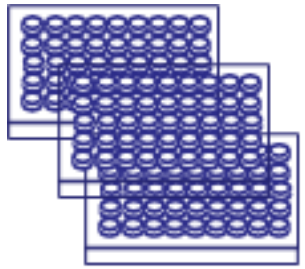


Thousands of Chemicals

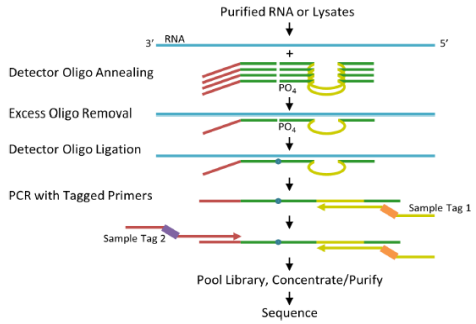


Multiple Cell Types

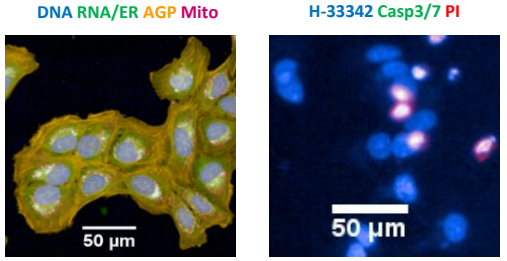
Concentration Response Screening



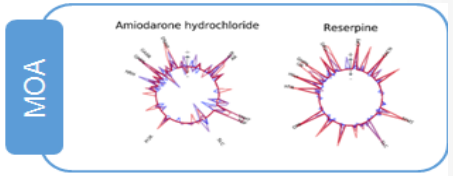
Whole Genome Transcriptomics



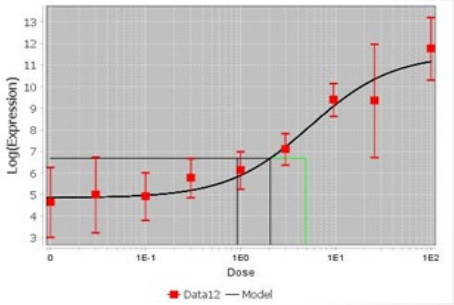
Multi-Parameter Cellular Phenotypic Profiling



Mode-of-Action Identification



Concentration Response Modeling



- 384-well, laboratory automation compatible
- Relatively inexpensive ($2.50 - $1,500 per chemical)
- Broad complementary coverage of molecular and phenotypic responses
- Integration of reference materials and controls for performance standards

Nyffeler et al. SLAS Discov. 2021 Feb;26(2):292-308. doi: 10.1177/2472555220950245
Harrill et al. Toxicol Sci. 2021 Feb 4;kfab009. doi: 10.1093/toxsci/kfab009. Online ahead of print

Incorporating High-Content Technologies to Increase Biological Coverage: Ecological Hazard

Daphnia magna

Pimephales promelas

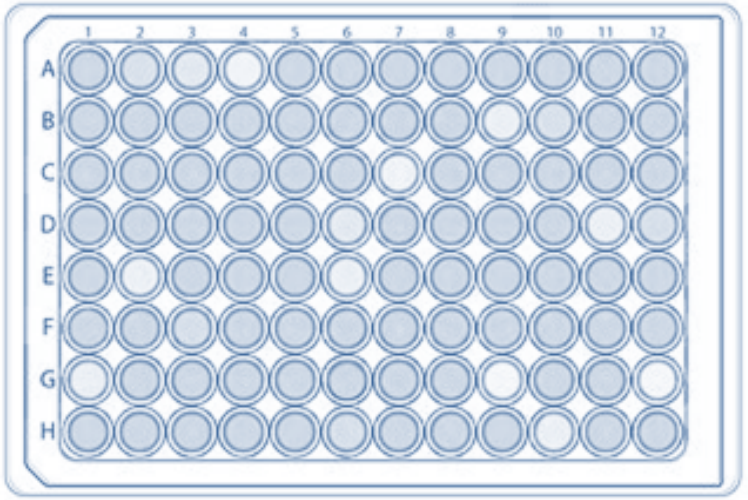
Chironomus dilutus

Raphidocelis subcapitata

- Modify standard protocols and methods to allow rapid toxicity tests with small aquatic organisms in 96-well plates – 4 species
- Conduct exposures with diverse chemicals (ex. metals, neonics, pharmaceuticals, PFAS)
- Compare traditionally derived LC50 values to LC50 values calculated from 96-well plate-based exposures
- Use RNA-seq data to calculate transcriptomic-based point-of-departure (tPODs) that can be anchored to apical responses

Slide courtesy of Dan Villeneuve

Evaluating Cross-species Differences in Nuclear Receptor-Ligand Interactions using a Multiplexed In Vitro Bioassay

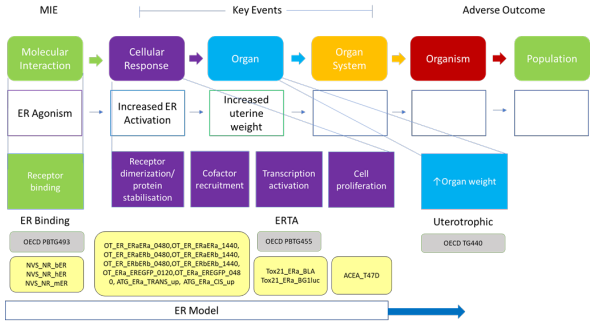


- Five species intended to capture maximum variability in PPARγ, PPARα, RXRβ, and GR sensitivity were selected for incorporation into a multiplexed in vitro bioassay.
- Species-specific differences in sensitivity were detected for all ligands tested as well as for environmental samples.
- Results suggest that effects-based monitoring employing human cell lines may misrepresent hazard to aquatic organisms for certain NRs.
- Screening of additional chemicals in the assay developed may provide new insights into predicting cross-species sensitivity based on amino acid sequence conservation.

Slide courtesy of Dan Villeneuve

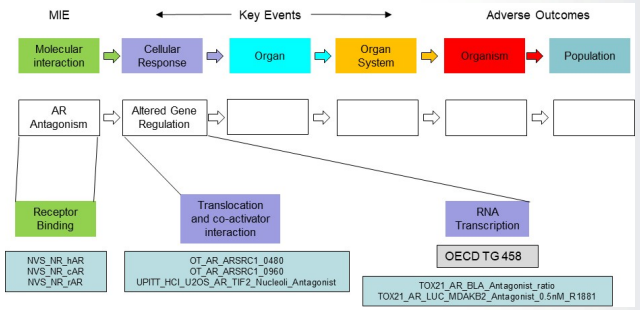
Orthogonal In Vitro Assays and Computational Modeling

- Developed multiple high-throughput screening assays
  - Use multiple assays per pathway
    - Different technologies
    - Different points in pathway
  - No assay is perfect
    - Assay Interference
    - Noise
- Use a computational model to integrate assays
  - Model creates a composite dose-response curve for each chemical to summarize results from all assays



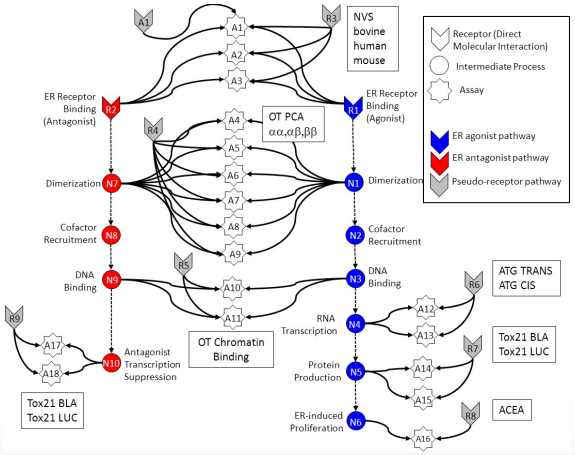
Estrogen Receptor Computational Model

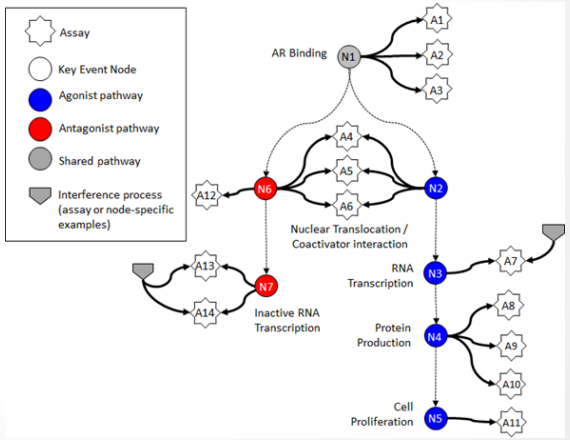
Judson et al., Envi Health Pers (2015)



Androgen Receptor Computational Model

Kleinstreuer et al., Chem Res Toxicol (2017)





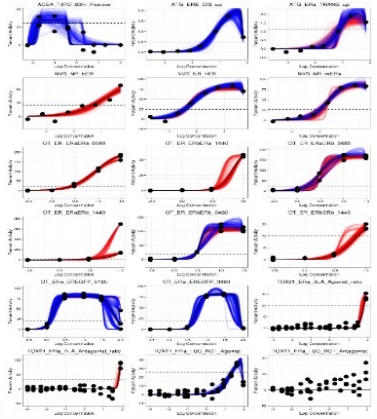
Uncertainty Analysis

Major sources of uncertainty:

1. Qualitative: is an assay "hit" really due to ER/AR activity, or assay interference?
2. Quantitative: uncertainty around the true potency value (AC50)

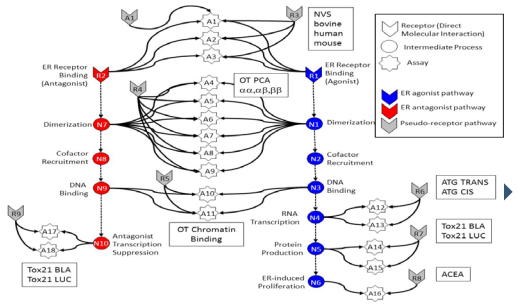
Both are now incorporated into the ER and AR model results through the development of statistical methods have been developed to establish uncertainty bounds around potency and efficacy values. These statistical methods involve resampling the data and refitting the concentration response curves thousands of times to quantitatively estimate the uncertainty.

Bootstrap Uncertainty in *In Vitro* Potency Values



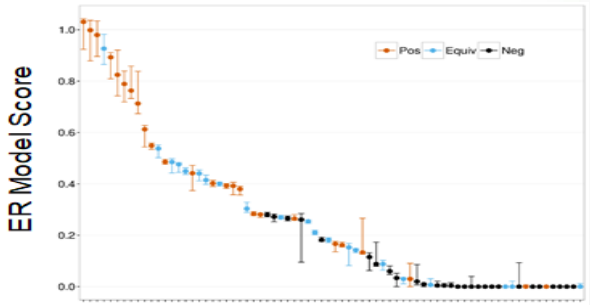
18 ER *In Vitro* Assays

Computational Modeling

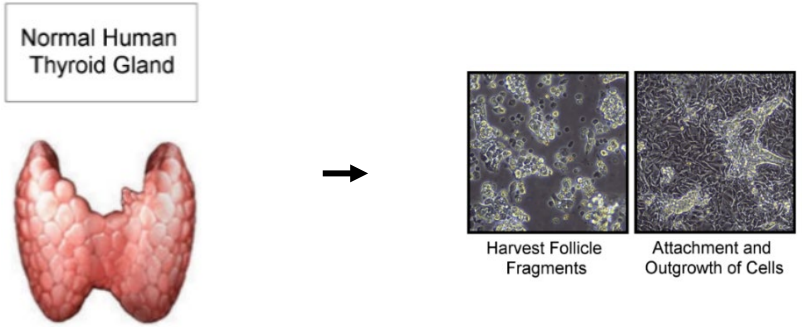


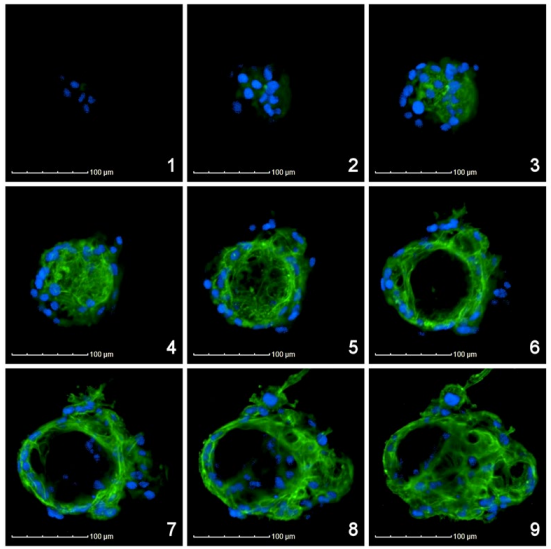
ER Pathway Model

Propagation of Uncertainty in Modeling Output

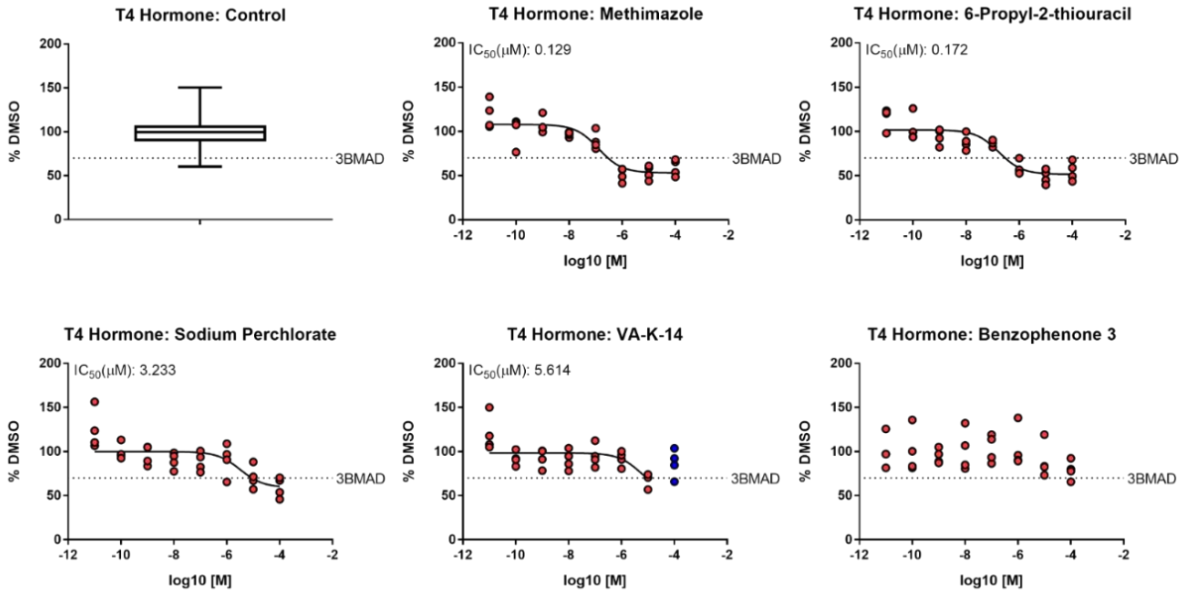


Developing Organotypic Culture Models to Identify Tissue/Organ Effects



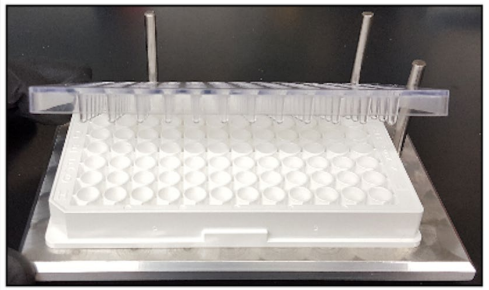


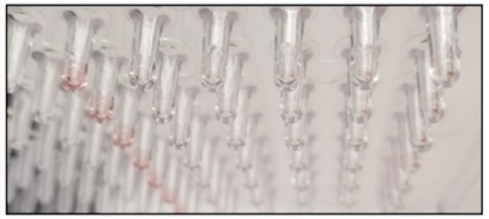
Blue, Hoechst 33342 /DNA
Green, Phalloidin/Actin

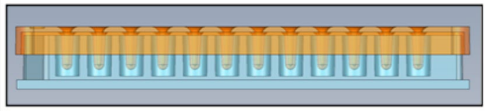


Deisenroth et al. Toxicological Sciences, Volume 174, Issue 1, March 2020, Pages 63-78, https://doi.org/10.1093/toxsci/kfz238

Metabolic Competence

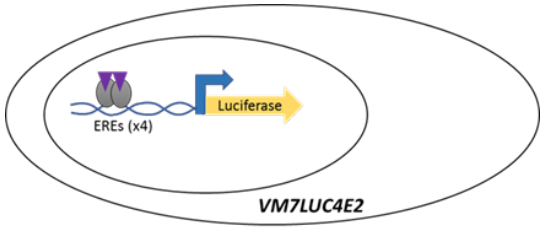


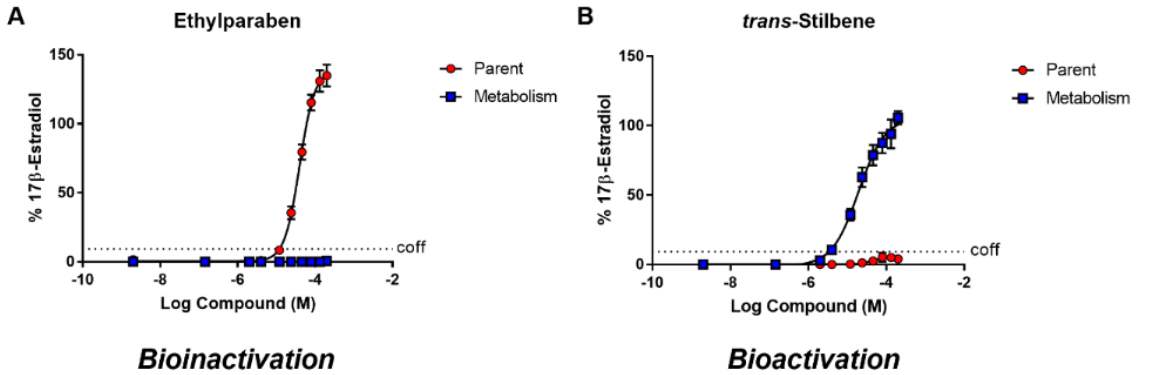




Alginate Immobilization of Metabolic Enzymes (AIME) Method: S9 fraction immobilization in alginate microspheres on 96- or 384-well peg lids

- **Retrofitting Metabolism**: AIME method suitable for biochemical- and cell-based HTS assays
- **Screening Throughput**: Adaptable to 96- and 384-well screening platforms
- **Regulatory Relevance**: Integration of phase I liver metabolism for hazard identification of parent and metabolite endocrine activity
- **Results:** Evaluation of a 63 chemical test set supports metabolic screening for -
  - Refinement of prioritization for ER-active substances based on metabolite effects
  - In some cases, supports more accurate prediction of *in vivo* effects for biotransformed substances





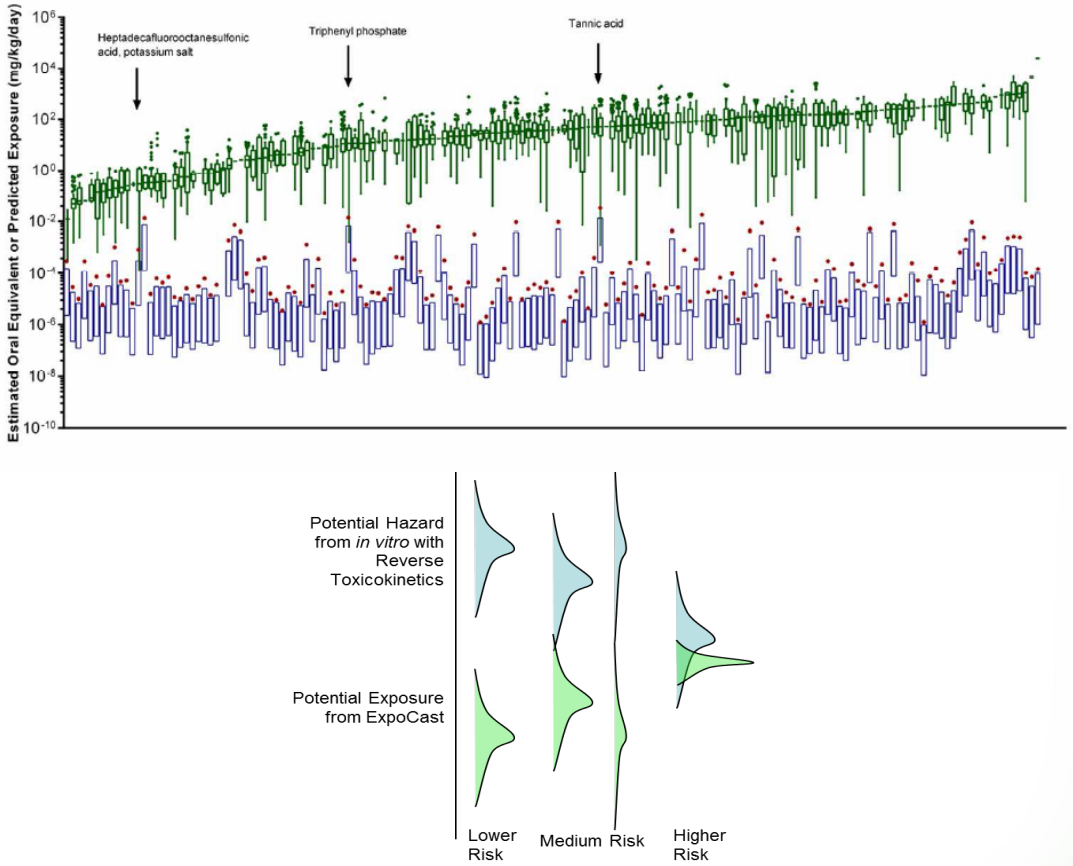
Parallel evaluation of parent compound and metabolites identifies false positive and false negative effects

Collaboration with Unilever

Deisenroth et al. Toxicological Sciences, Volume 178, Issue 2, December 2020, Pages 281–301, https://doi.org/10.1093/toxsci/kfaa147

Linking Bioactivity and Exposure (*i.e.* Risk)

- **High throughput risk characterization** relies on three components:
  1. High throughput **hazard** (*i.e.* bioactivity) characterization
  2. High throughput **exposure** forecasts
  3. High throughput **toxicokinetics** (*i.e.* dosimetry)

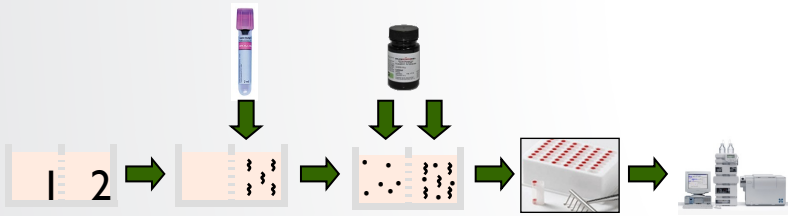


SAP Dec 2014: http://www2.epa.gov/sap/meeting-materials-december-2-4-2014-scientific-advisory-panel
Judson 2011 (https://doi.org/10.1021/tx100428e)
Wetmore 2015 (https://dx.doi.org/10.1093%2Ftoxsci%2Fkfv171)
Wambaugh 2019 (https://doi.org/10.1016/j.cotox.2019.07.001)

High throughput toxicokinetics (HTTK)

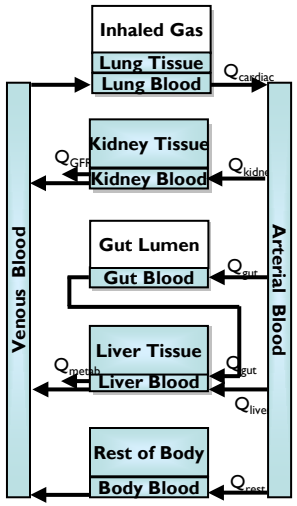
in vitro data

Hepatic clearance from suspended hepatocytes



Plasma protein binding

Generic toxicokinetic models



+

=

httk

Some high-level assumptions:

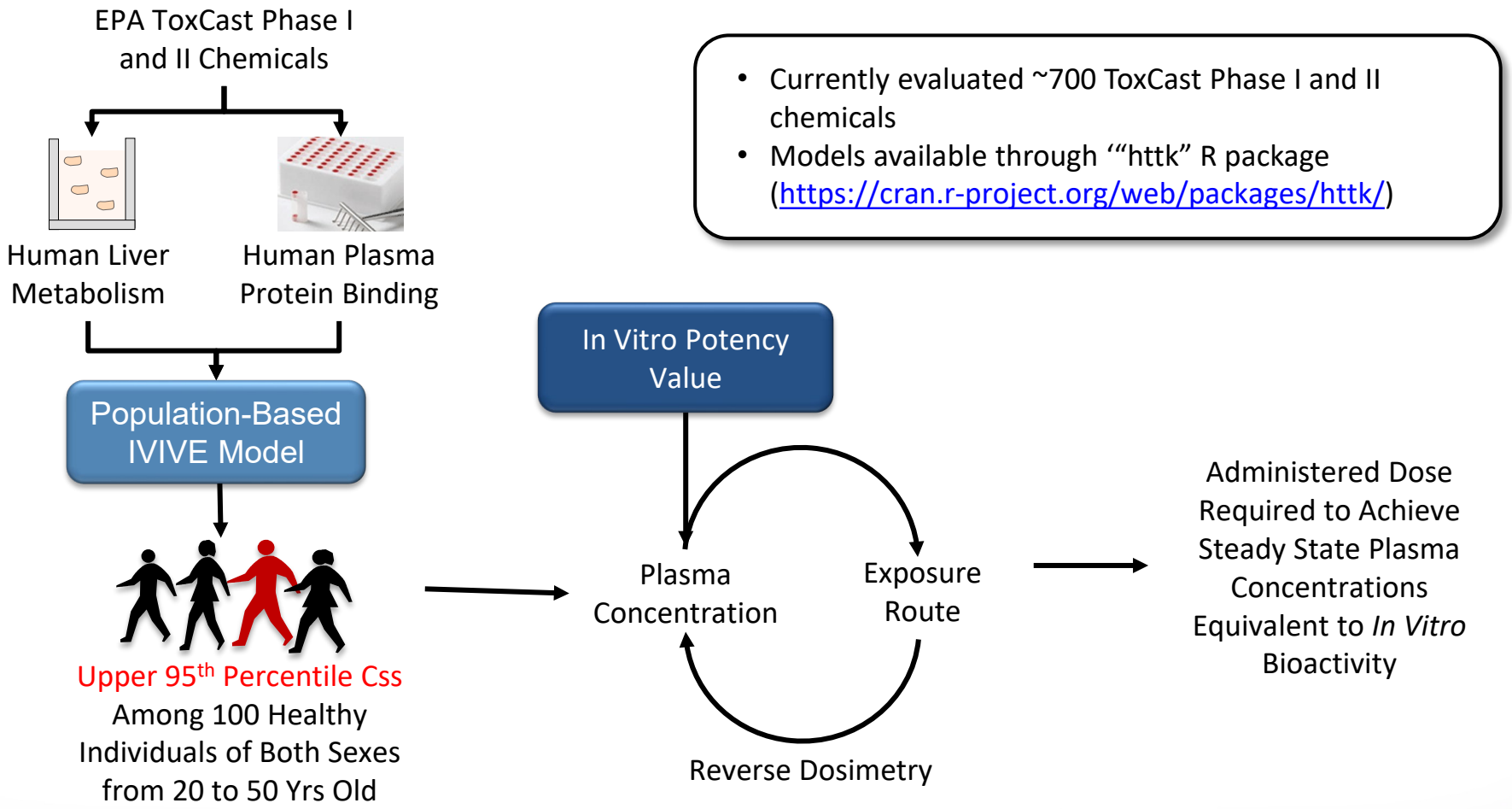
(1) bioactive nominal *in vitro* assay concentration ~ *in vivo* plasma concentration that would correspond to a similar effect;

(2) external exposures (in mg/kg/day units) that may have resulted in that plasma concentration can be constructed using estimates of species-specific physiology and Phase I and Phase II enzyme-driven hepatic clearance; and,

(3) Often, we expect that plasma concentration can be approximated by steady-state kinetics (unless we have enough information to use other dose metrics).

Led by John Wambaugh, Barbara Wetmore, and colleagues

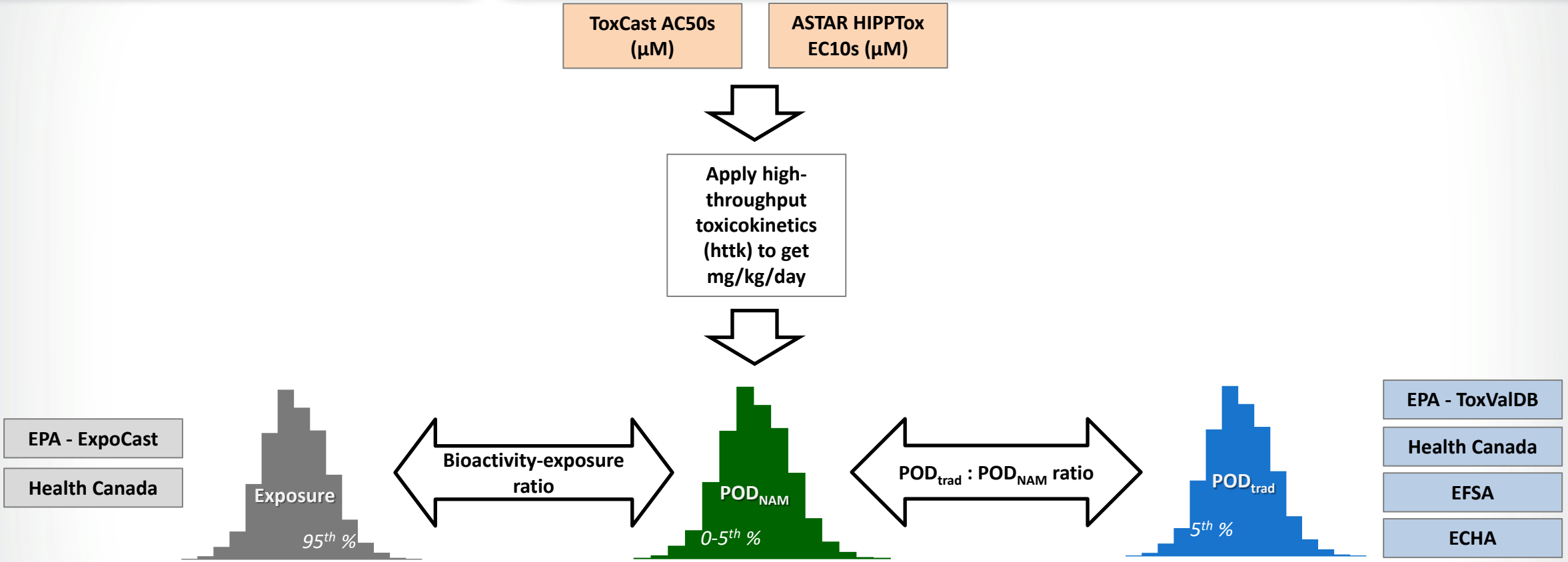
Adding the High-Throughput Toxicokinetic Component



- Currently evaluated ~700 ToxCast Phase I and II chemicals
- Models available through '"httk" R package (https://cran.r-project.org/web/packages/httk/)

Rotroff *et al., Tox Sci.*, 2010
Wetmore *et al., Tox Sci.*, 2012
Wetmore *et al., Tox Sci.*, 2015

Development of a POD_{NAM}

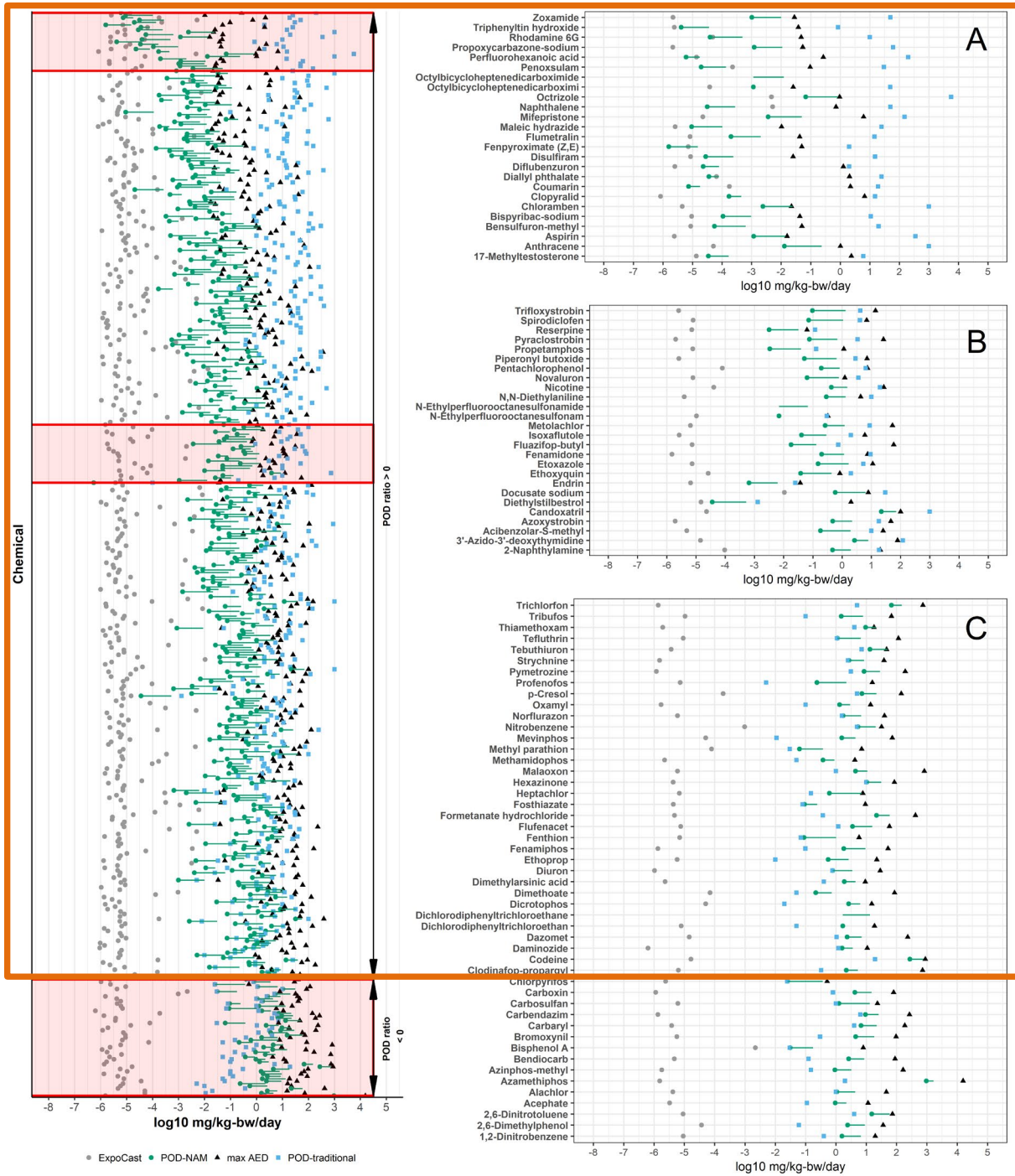


Is BER useful for prioritization?
Are there addressable weaknesses?

Is log10-POD ratio > 0 for most chemicals?
Can we learn from log10-POD ratio < 0?

- *NOEL, LOEL, NOAEL, or LOAEL*
- *Oral exposures*
- *Mg/kg/day*

Paul Friedman et al. *2020 Toxicol Sci. 2020 Jan 1;173(1):202-225. doi: 10.1093/toxsci/kfz201.*



400/448 chemicals =
89% of the time this naïve approach appears conservative

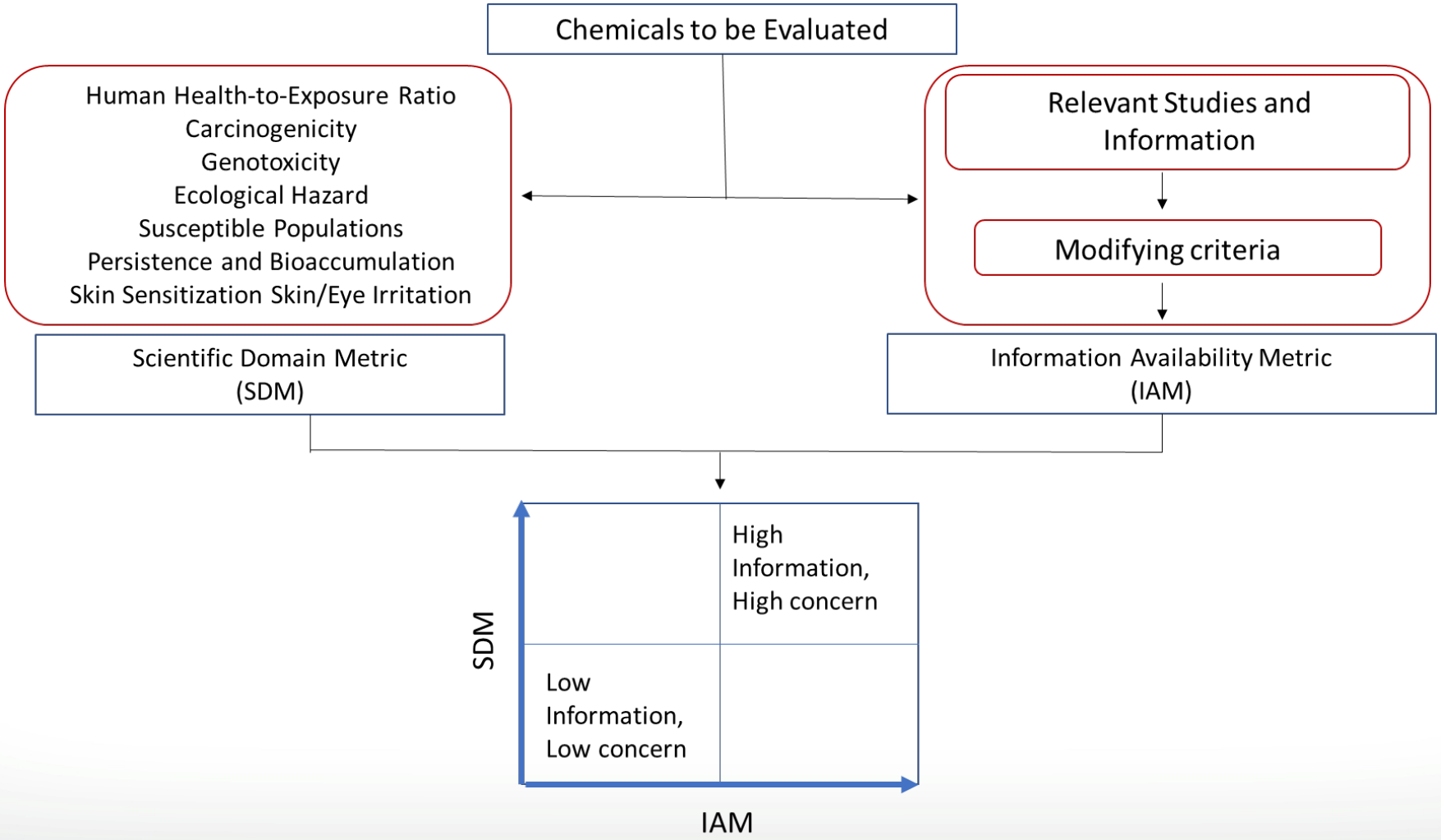
$POD_{NAM} < POD_{traditional}$

(most of the time)

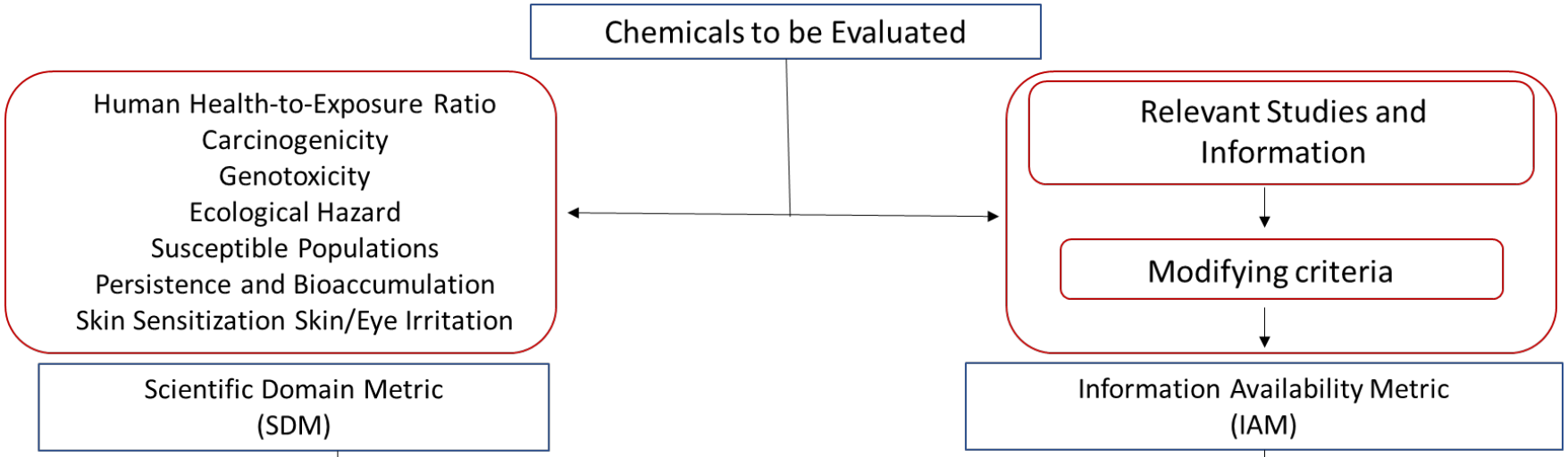
48/448 chemicals =
11% where $POD_{NAM} > POD_{traditional}$

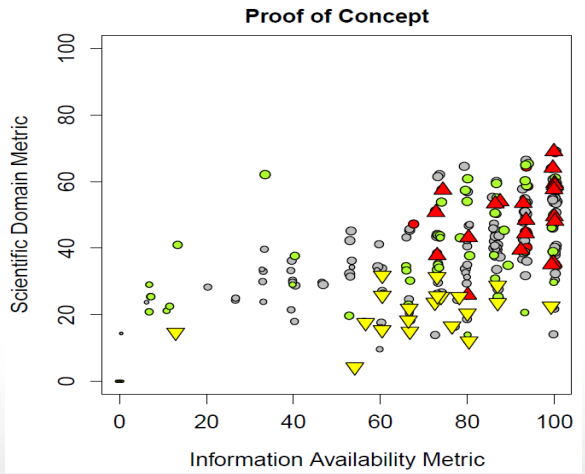
Paul Friedman et al. *2020 Toxicol Sci. 2020 Jan 1;173(1):202-225. doi: 10.1093/toxsci/kfz201.*

Public Information Curation and Synthesis (PICS) Approach

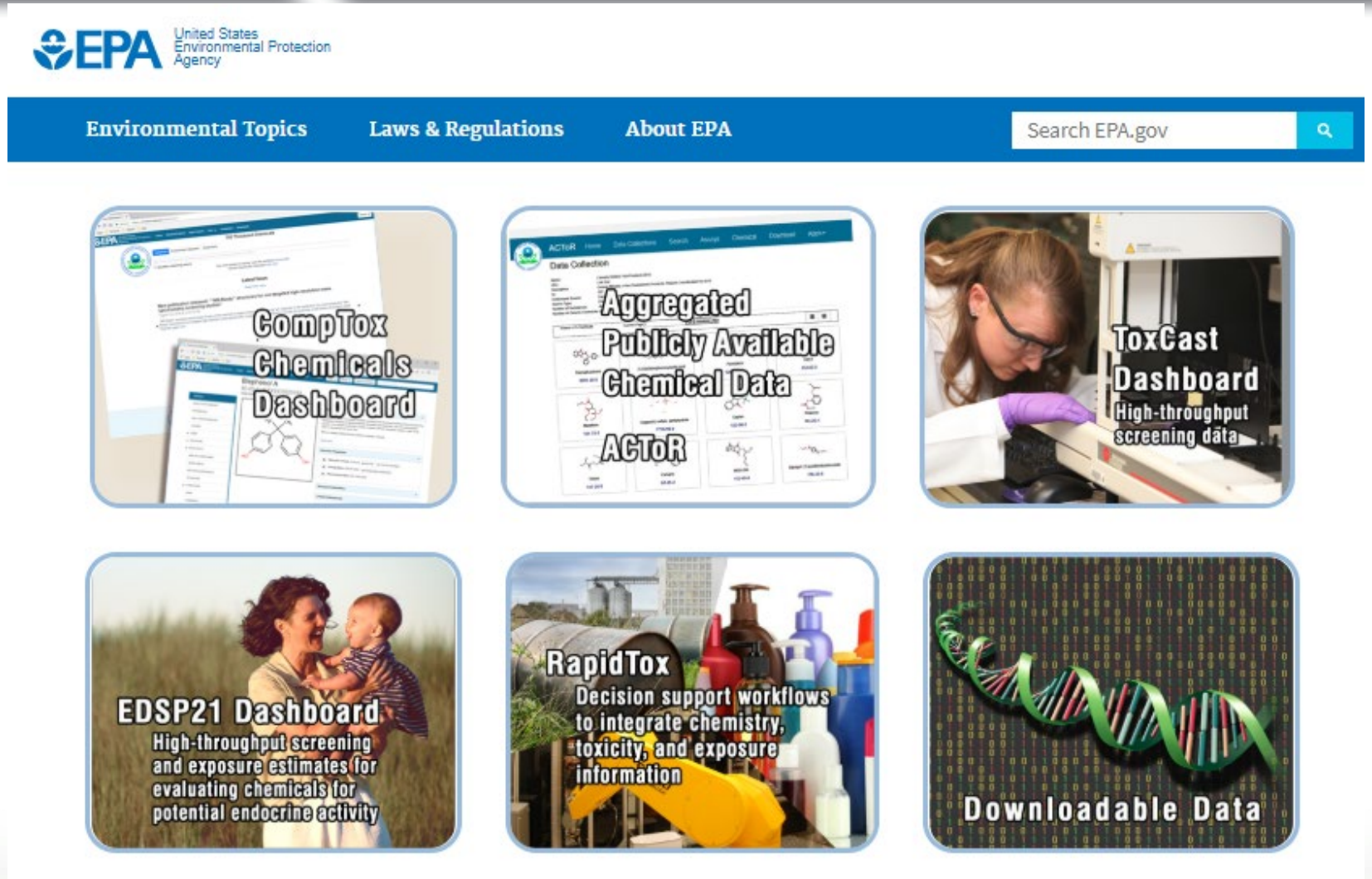


Public Information Curation and Synthesis (PICS) Approach





Provide Data Through Support Dashboards



The CompTox Portal (http://comptox.epa.gov)

Questions?