Relative Importance of PFAS Exposure Sources for the General U.S. Population

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Biomonitoring California
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SCHOOL OF
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Presentation topics

- Which PFAS are we talking about?
- Methods for investigating exposure to PFAS
- Major exposure routes:
  - Water
  - Diet
  - Other, including indoor exposure (also Kate Hoffman)
- Relative contributions

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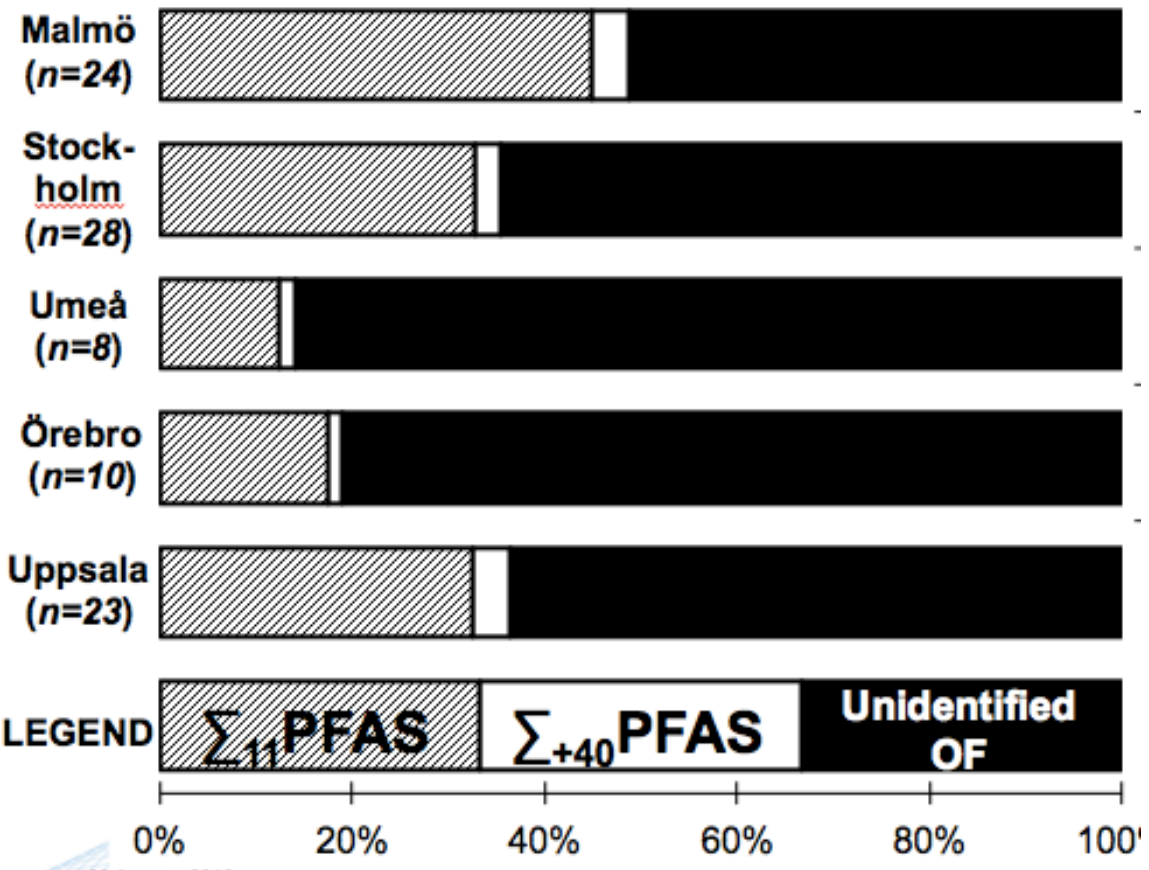
Substantial amounts of unidentified organofluorine (OF) in human blood, environmental media, consumer products

e.g., Swedish whole blood samples



- **EOF/TOF + targeted + NT analysis provides a powerful mass balance approach (Miyake et al 2007, Yeung et al 2009)**

Aro R, et al. 2019

What is the unexplained organofluorine?

- **PFAS we are not measuring (e.g., due to lack of standards) or something else?**
- **Likely depends on media, e.g., waste water (e.g., side chain fluorinated polymers) vs. human serum**
- **Depends on the definition of PFAS!**

What is a PFAS? (at least 8 definitions)

Buck et al (2011):

"Aliphatic substances containing one or more C atoms on which all the H substituents present in the nonfluorinated analogues from which they are notionally derived have been replaced by F atoms, in such a manner that PFASs contain the perfluoroalkyl moiety C_nF_{2n+1}–."

aliphatic

$–CF_3$

(- ≠ H)

OECD 2021

"PFASs are defined as fluorinated substances that contain at least one fully fluorinated methyl or methylene carbon atom (without any H/Cl/Br/I atom attached to it), i.e. with a few noted exceptions, any chemical with at least a perfluorinated methyl group (–CF3) or a perfluorinated methylene group (–CF2–) is a PFAS."

$–CF_3$ or

$–CF_2–$

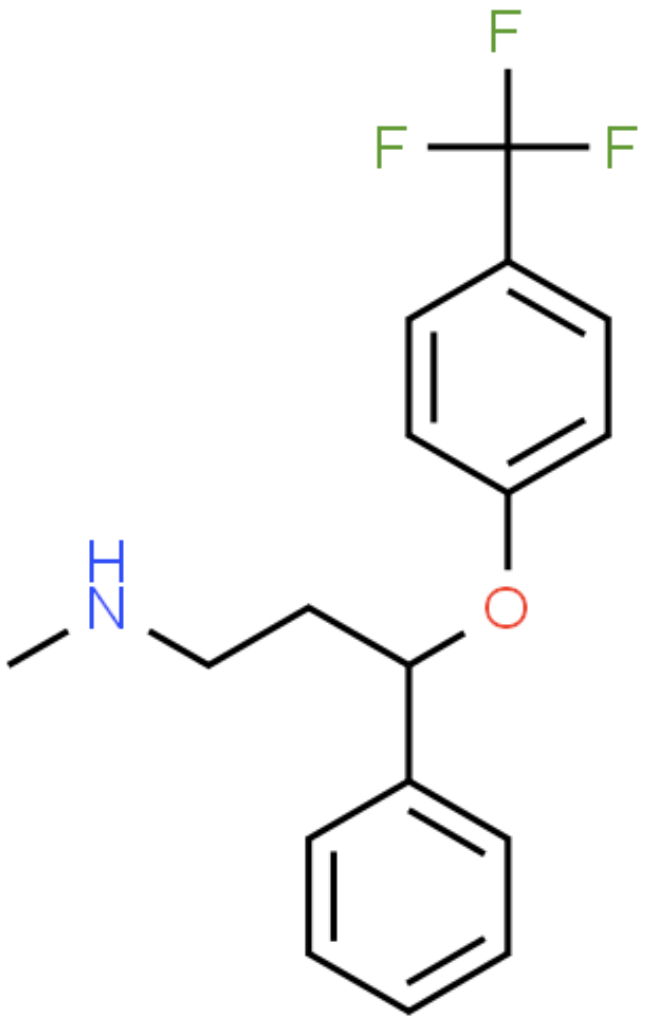
(- ≠ H,Cl,Br)

Several state laws

"fluorinated organic chemicals containing at least one fully fluorinated carbon atom"

much broader!

One example of a major fluorinated pharmaceutical included under the OECD definition, but not under Buck et al



Fluoxetine (Prozac)

Hammel et al. 2021

Caveat:

When we talk about exposure to PFAS, we usually mean a handful of legacy PFAS such as PFOA/PFOS for which there are data

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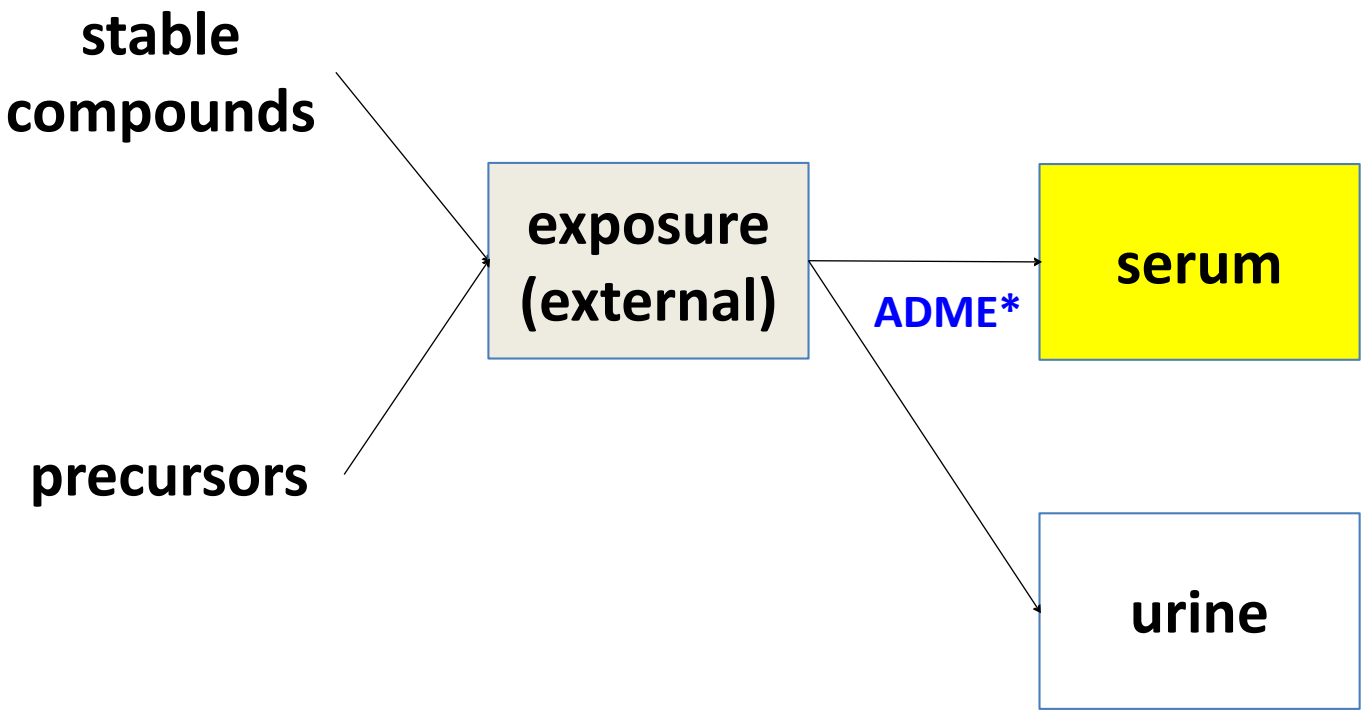
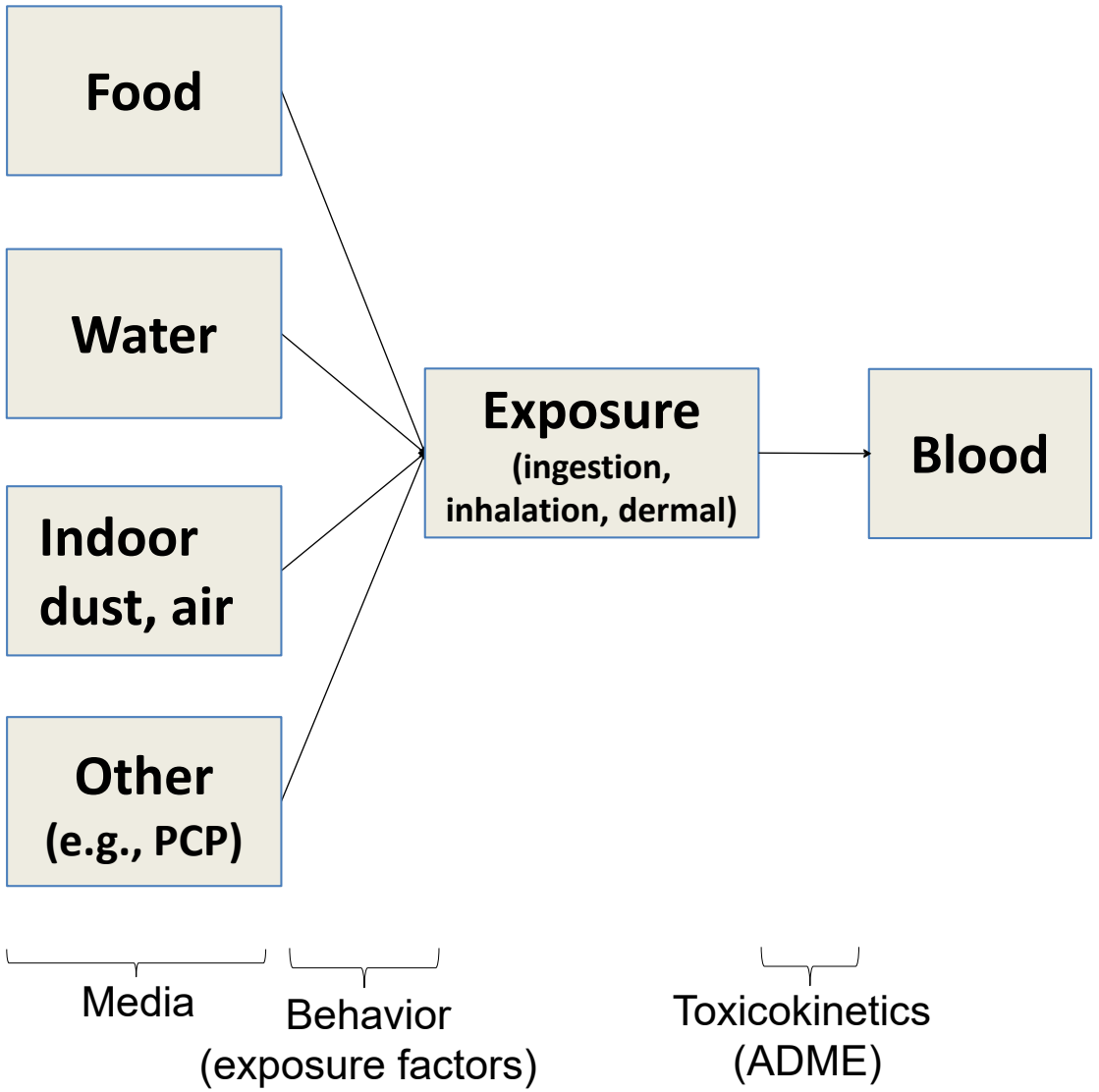
Biomonitoring for PFAS

- Mostly using serum or plasma
- Persistent compounds that we target (e.g., PFOA)
  - Resulting from direct exposure or precursors (e.g., FTOHs)



* ADME = absorption, distribution, metabolism, elimination

Biomonitoring integrates exposure routes



PCP = personal care products

not all exposure routes shown, e.g., outdoor air near industrial sources

Exposure: 2 main approaches* (illustrated for water)

- **"Epidemiologic":**
  regress serum PFAS concentrations vs. water concentration
- **Exposure factor:**
  (water concentration) X (water consumption rate)

*** each with strengths & weaknesses**

Exposure: 2 main approaches

- **"Epidemiologic":**
  regress serum PFAS concentrations vs. water concentration
- **Exposure factor:**
  (water concentration) X (water consumption rate)

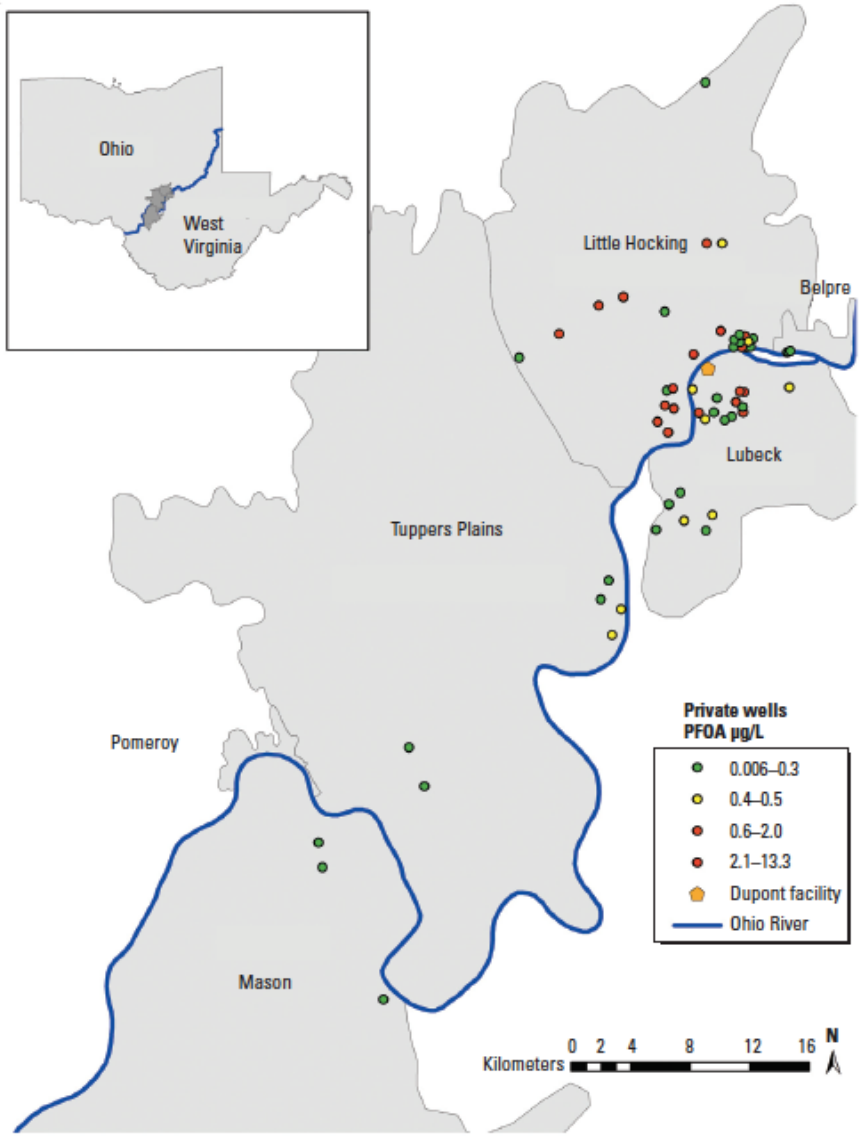
Also:

- **Chemometrics, e.g., principal component analysis ("fingerprints")**
  do the patterns of different PFAS tell us about sources?
- **Reverse dosimetry**
  do estimates of total exposure from reverse dosimetry roughly match estimates from other methods?

Presentation topics

- Which PFAS are we talking about?
- Methods for investigating exposure to PFAS
- **Major exposure routes:**
  - **Water**
  - **Diet**
  - **Indoor exposure (also Kate Hoffman)**
  - **Other**
- Relative contributions

Water: "Epidemiologic" studies show importance in contaminated areas (AFFF, industrial sources)



PFOA water concentrations in C8 study area (West Virginia/Ohio) predict serum levels near an industrial production facility

Each 1 µg/L increase in PFOA levels in drinking water was associated with an increase in serum concentrations of 141.5 µg/L (95% CI=134.9 –148.1)

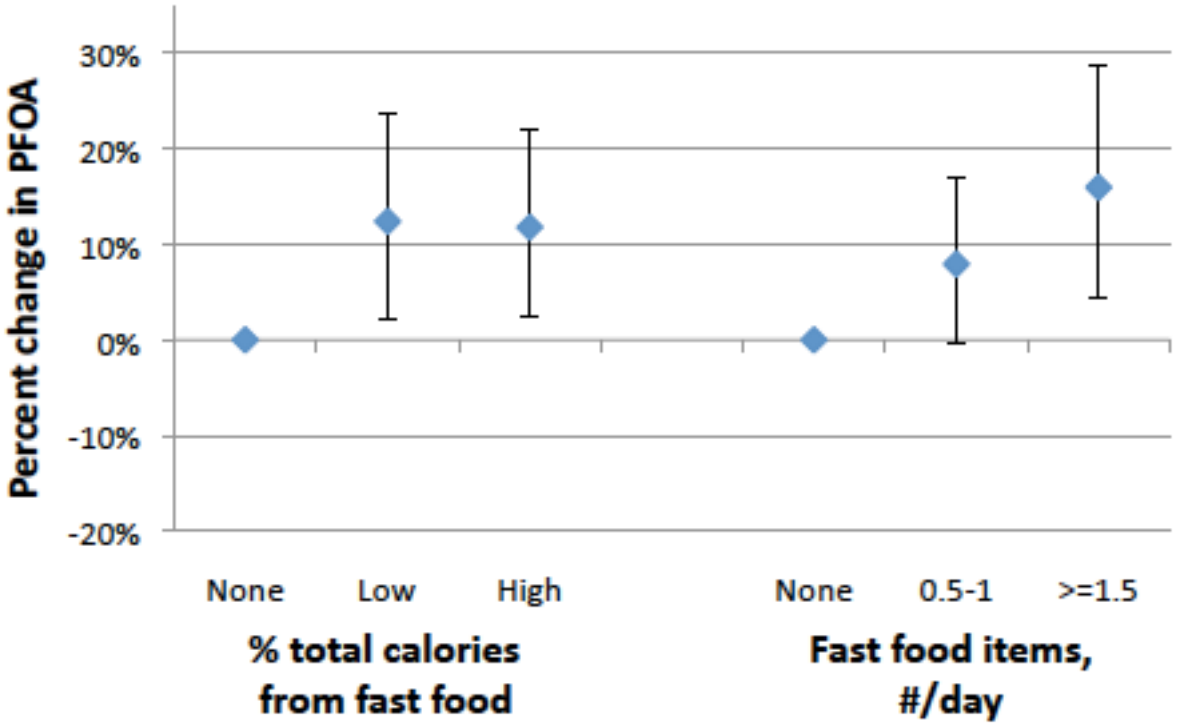
Consistent with pharmacokinetic estimates (based on half-life and volume of distribution)

Hoffman et al 2011

Diet: Several US "epidemiologic" studies found diet significantly associated with blood levels (mostly older data), e.g.:

- **DPP 1996-1999: reported consumption of fried fish, other fish/shellfish, meat and poultry had positive associations with many targeted PFAS plasma concentrations.**

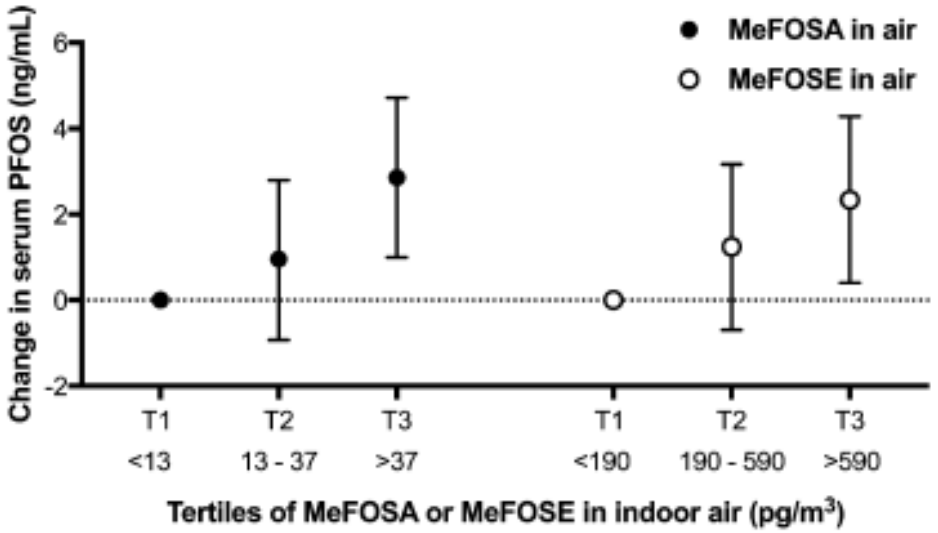
- **NHANES 2003-4 (USA)**
  red meat: PFOS, PFNA



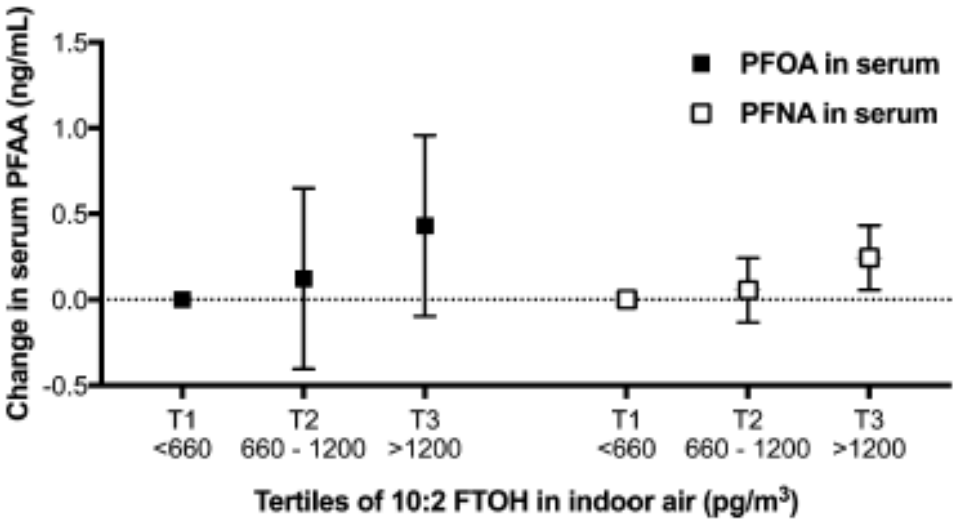
Lin et al. 2021.
Nelson et al 2010

Indoor exposure: several “epidemiologic” studies

- serum concentrations associated with air concentrations of the more volatile compounds (e.g., FTOHs)
- serum and dust not associated or weakly



e.g., indoor air levels of MeFOSA & MeFOSE predict PFOS serum levels, pregnant women, Vancouver

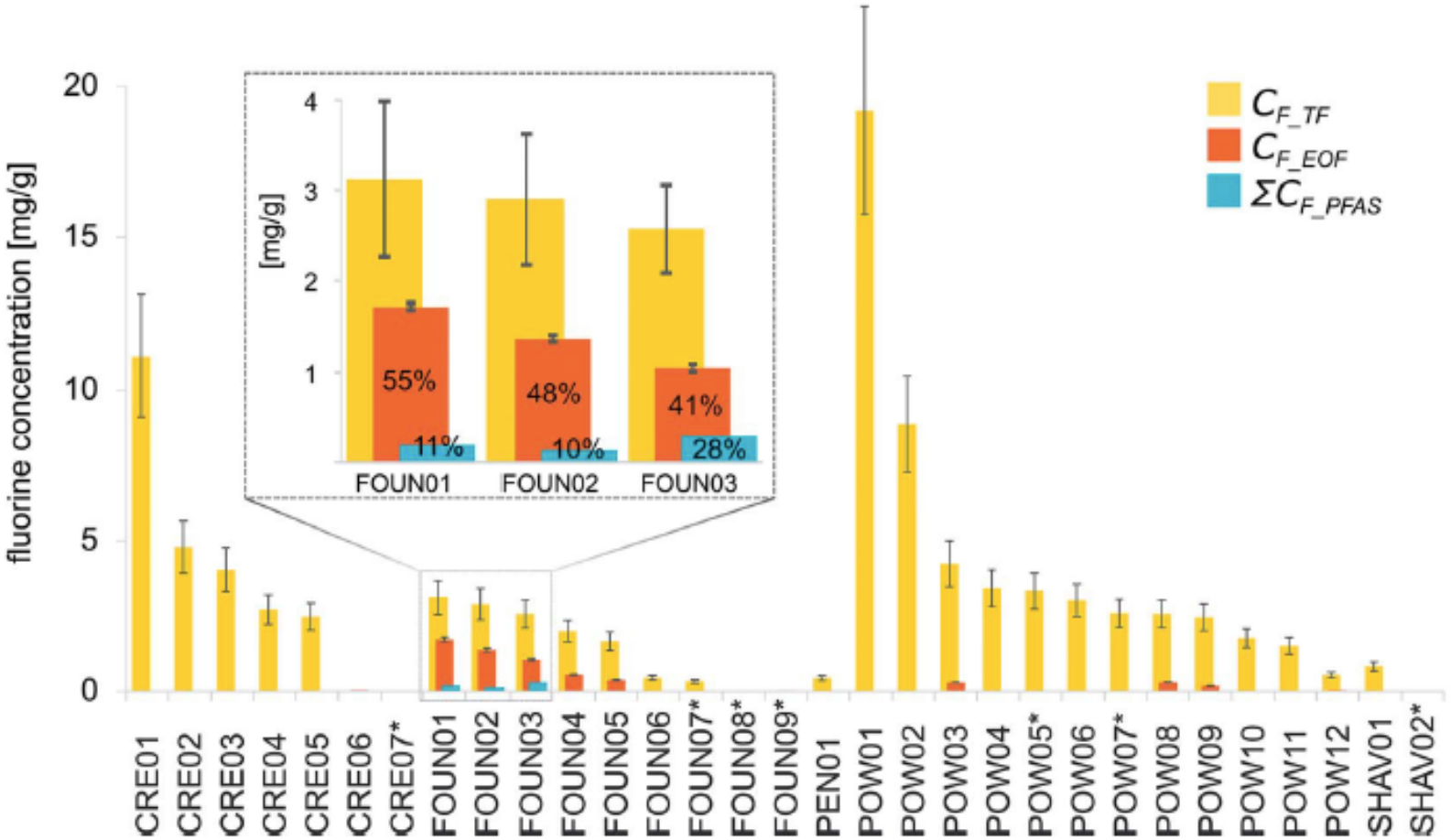


e.g., indoor air levels of 10:2 FTOH predict PFOA & PFNA serum levels, pregnant women, Vancouver

Makey et al. 2017

Other (e.g., personal care products)

- High levels of total fluorine, EOF, PFAS found in some cosmetics
- PFAS << EOF << total fluorine
- Potential for high dermal exposure: needs more experiments



Schultes L et al. 2018

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Water, US general population

- **Stored water and serum from 1989-90**
- **Tap water PFOA and PFNA significantly predicted plasma Concentrations among individuals who consumed ≥8 cups of tap water per day**
- **Estimated water accounted for about 12% of blood PFOA, 13% for PFNA**

Hu et al 2019

Relative contribution estimates

- **Most relative contribution studies use the exposure factor approach**
- **Substantial uncertainties, e.g.,**
  - **where/how sample and measure PFAS in media, especially food**
  - **precursors?**
  - **conversion rates of precursors**
  - **dust ingestion rates very uncertain**
  - **dermal exposure poorly understood for PFAS**

Exposure factor estimates (%) for adults: diet as main source (very uncertain)

		Exposure medium[b]				Exposure route[b]				
PFAS	Carbon length	Diet	Dust	Water	Consumer goods	Inhalation	Dermal	Indirect	Study location	Ref.
PFBA	4		4	96					NA	c
PFHxA	6	38	4	38		8		12	NA	c
PFHxA	6	87	4			2			Norway	d
PFHxS	6	57	38			5			Finland	e
PFHxS	6	94	1						Norway	d
PFHpA	7	93	1						Norway	d
PFHpS	7				100				Norway	d
PFOA	8	16	11		58	14			NA, EU	f
PFOA	8	85	6	1	3			4	Germany, Japan	g
PFOA	8	77	8	11		4			Norway	h
PFOA	8	66	9	24		<1	<1		USA	i
PFOA	8	41		37				22	Korea	j
PFOA	8	99		<1					China	k
PFOA	8	47	8	12		6		27	NA	c
PFOA	8	95	<2.5			<2.5			Finland	e
PFOA	8	89	3			2			Norway	d
PFOA	8	91		3		5			Ireland	l
PFOS	8	66	10	7		2		16	NA	c
PFOS	8	72	6	22		<1	<1		USA	m
PFOS	8	96	1	1		2			Norway	h
PFOS	8	81	15		4				NA, EU	f
PFOS	8	93		4				3	Korea	j
PFOS	8	100		<1					China	k
PFOS	8	95	<2.5			<2.5			Finland	e
PFOS	8	75				3			Norway	d
PFOS	8	100							Ireland	l
PFOPA	8		100						Norway	d
PFNA	9	79	5			1			Norway	d
PFDA	10	51	2	4		15		28	NA	c
PFDA	10	78	1			2			Norway	d
PFDS	10		89		4				Norway	d
PFUnDA	11	61	4			1			Norway	d
PFDoDA	12	86	2	2		4		5	NA	c
PFDoDA	12	48	15						Norway	d
PFTrDA	13	89	1						Norway	d

De Silva et al. 2021

2011 US exposure factor estimates (%) for adults: diet as main source (very uncertain)

	diet	dust	water	inhalation	dermal
PFOA	66	9	24	<1	<1
PFOS	72	6	22	<1	<1

Lorber & Egeghy 2011 as reported in De Silva et al 2021

Relative importance of pathways (for a few legacy PFAS)

- **Water, diet and indoor air all predict blood levels of some PFAS in some populations**
- **Water very important in contaminated areas**
- **Diet generally thought to be the major route of exposure to PFOA & PFOS for general population in uncontaminated areas, but substantial uncertainties**
- **Contrast EFSA & FDA studies of diet**
- **Importance of personal care products??**

- **Need for comprehensive exposure studies—will require intensive sampling.**

Some trends to consider due to changing PFAS production & use:

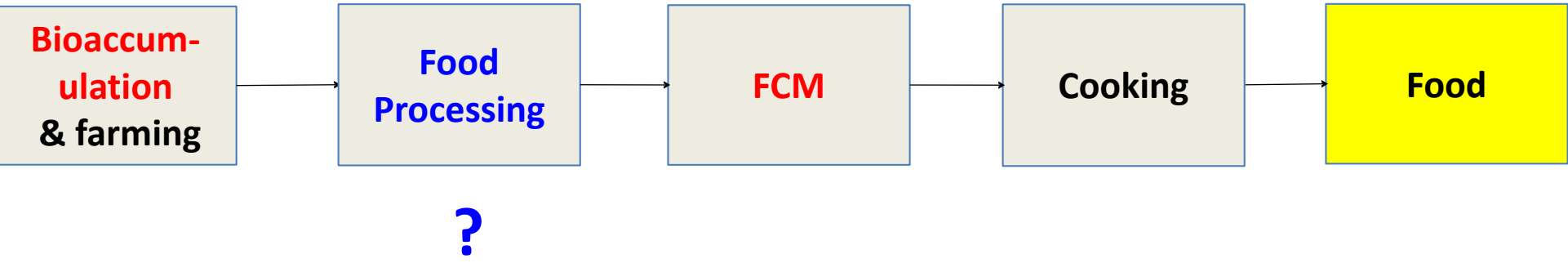
- **“Fast” consumables (e.g., food packaging, cosmetics)—quick turnover implies rapid changes in exposure**
- **“Slow” consumables (e.g., furniture)—slow changes in exposure**
- **Global distribution of persistent, mobile compounds**
- **Diet: shifting food packaging implies bioaccumulation may become more important for some PFAS**

NOTE: exposure (external) may decline faster than PFAS measured in serum with long halflives

Scientifically, we need a better understanding of

- **Unidentified organofluorines in blood, environment, products: identity? sources?**
- **Dietary exposure to PFAS in USA & sources in food**
- **Indoor sources**
- **Dermal exposure, e.g., from cosmetics**
- **Relative source contribution to serum PFAS**
- **Updated exposure studies addressing changing production & use**

PFAS getting into food via both bioaccumulation and Food Contact Materials (FCM)



- Depends on food and type of PFAS
- Teflon pans generally thought not to be a major source?
- Food processing less studied

Some thoughts on what a biomonitoring surveillance program can do regarding PFAS exposure

Public health

- **Point out exposure to water in contaminated communities using location (science well established)**
- **Monitor time trends & evaluate interventions (although lag when long human halflives)**
- **Disparities**

Research

- **Use of limited questionnaire data to examine exposure from non-water sources, e.g., consumption of certain foods, carpet**
- **This has been successfully done before, e.g., NHANES. Limitations include questionnaire data, time lags, direct exposure + precursors**
- **Chemometric "fingerprints"**

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National Institute of Environmental Health Sciences

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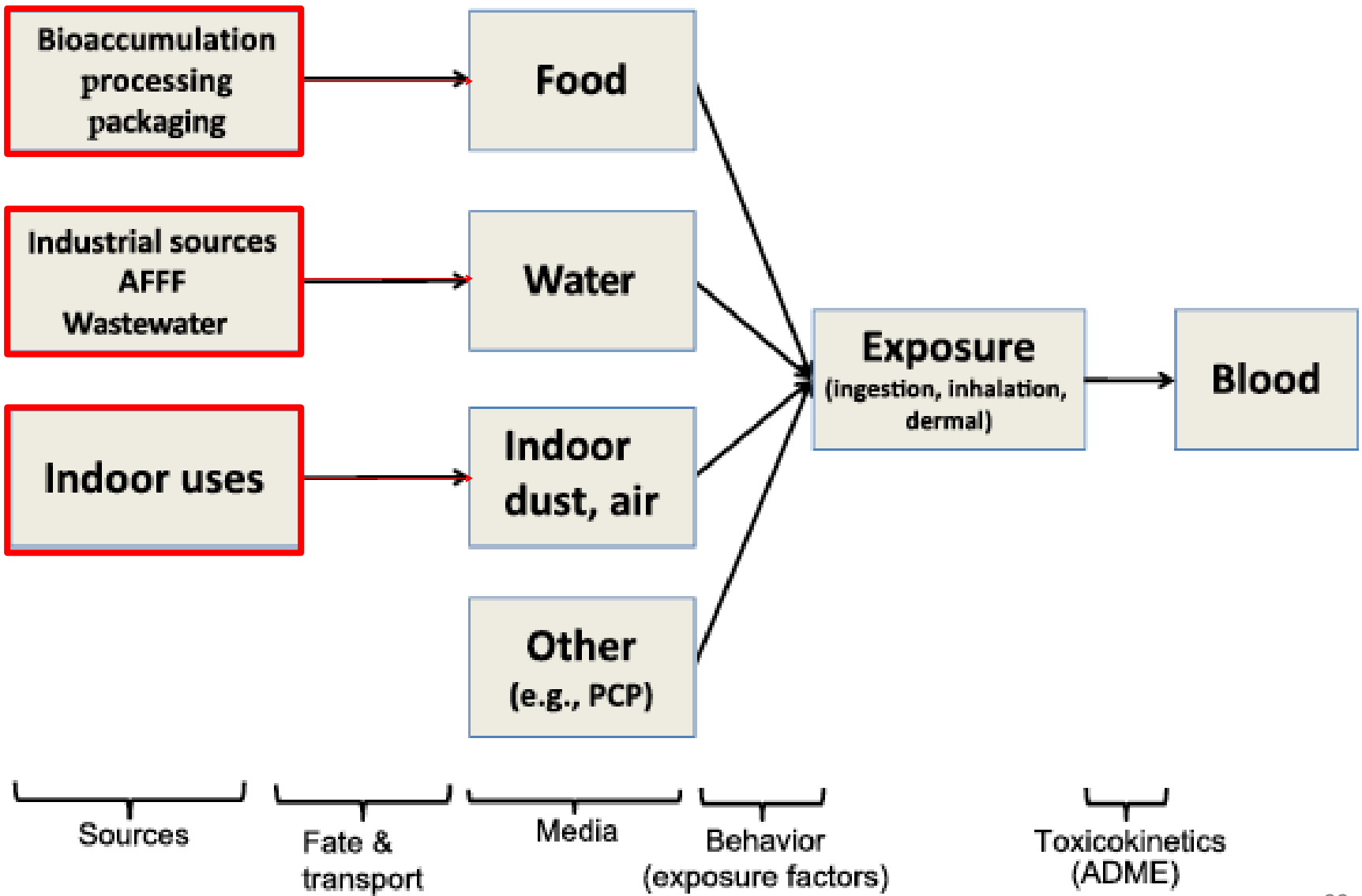
Sources of exposure, large local & diffuse/global sources



De Silva et al. ETC 2021