Title

Development of a Data Visualization Tool for Occupational Exposure to Chemicals of Concern for Breast Cancer Among California Working Women, 2010–2014

Journal

New Solutions, 31(4)

Author

Beckman, Stella

Publication Date

2021-07-29

Peer reviewed

NEW SOLUTIONS: A Journal of Environmental and Occupational Health Policy
2022, Vol. 31(4) 400–412

DOI: 10.1177/10482911211032971
journals.sagepub.com/home/new
SAGE

Development of a Data Visualization Tool for Occupational Exposure to Chemicals of Concern for Breast Cancer Among California Working Women, 2010–2014

Stella Beckman[1], Elana Silver[2], Justine L. Weinberg[3], Susan Hurley[1], Matt Frederick[3], Jacqueline Chan[3], Peggy Reynolds[1], and Robert Harrison[3]

Abstract

We identified the occupations that employ California women and a list of chemicals of concern for breast cancer. We evaluated the likelihood of on-the-job exposure to the categories of chemicals by occupation among formally and informally employed women. We selected 145 occupations representing more than 6.6 million women (85% of California working women), along with an additional sixteen occupations for informal workers only. We organized 1012 chemicals (including mammary gland carcinogens, developmental toxicants, and endocrine-disrupting chemicals) into twenty-five categories. More than 80 percent of occupations investigated had possible or probable exposure to at least one category of chemicals. This is the first categorization of occupational exposure to chemicals of concern for breast cancer among California working women. Our investigation revealed significant data gaps, which could be improved by policy changes resulting in enhanced collection of data on occupation and chemical exposure.

Keywords

breast cancer, occupation, chemical exposure, informal workers

Introduction

Despite decades of intensive research, the causes and basic biology of breast cancer remain unclear, with an estimated 30–50 percent of all cases lacking an identified risk factor which may have contributed to causing the disease.[1] The rise in breast cancer incidence in the United States during the latter part of the past century was contemporaneous with the large-scale entry of women into the paid workforce. Despite the presence of seventy-two million women in the U.S. labor force in 2017,[2] occupational risk factors for women, especially chemical exposures in the workplace, remain relatively understudied.[3,4] Few of the estimated eighty-four thousand chemicals in commerce have been tested for carcinogenic potential;[5] however, at least two hundred have been identified as mammary carcinogens in animals.[6] Many more chemicals may be etiologically relevant to breast cancer due to their developmental toxicity or endocrine-disrupting properties.[7–9] Due to the historical underrepresentation of women in occupational health studies, little is known about workplace-related breast cancer risks, and there are no current national surveillance systems for occupational breast cancer or widespread systems for collection of occupational chemical exposure data.[3,4,10,11]

Elevated breast cancer risk has been documented in a number of industries and occupations. Occupations with likely chemical exposure include cosmetologists and beauticians, flight attendants, nurses, machinists, and agricultural workers.[12–14] Our research focused on potential for chemical exposure; however, other risk factors, including night shift work and ionizing radiation, may also be significant for some of these occupations.

[1]University of California San Francisco, CA, USA
[2]Laurelton Research, Oakland, CA, USA
[3]California Department of Public Health, Richmond, CA, USA

Corresponding Author:
Stella Beckman, University of California San Francisco, 2001 Center Street, Suite 700, Berkeley, CA 94704, USA.
Email: sfbeckman@ucdavis.edu

Industries with studies showing probable exposure to chemicals that may cause breast cancer include manufacturing, food canning, transportation, and agriculture.[3,13–19] These studies mostly lacked quantitative measures of chemical exposures and did not always identify specific chemicals, leaving the degree to which chemical carcinogens may contribute to these risks unknown.[3,13,14]

The objective of this research was to identify the jobs where most California women work, characterize the potential for exposure to chemicals of concern for breast cancer for those jobs, and display this information along with demographic data in a data visualization tool (graphic depiction of data using interactive components, visual representation, and numeric elements). We used the results of this work to identify sources of relevant data, describe gaps in these data, and propose suggested policy changes that could help fill these gaps. California is home to more than 8.3 million employed women age sixteen or older, with one of the most diverse workforces in the United States.[2] Because of the widespread recognition of enormous growth in the informal workforce over recent decades, we specifically aimed to make informal workers visible in the data visualization tool. Informal workers are those whose employer–employee relationships are unreported and untaxed, resulting in workers who are *de facto* not protected by occupational safety and health regulations.[20–23] Several comprehensive, generalizable assessments of large populations of workers have been constructed providing estimated exposure levels for various carcinogenic agents,[24–27] but the occupations and agents included were generally not relevant to California women. Other researchers have performed study-specific exposure assessments for chemicals of concern for breast cancer, but these assessments were focused on specific outcomes or limited lists of occupations and chemicals; they informed our methodology.[18,28–33] This tool and the underlying research are, to our knowledge, the first broad characterization of potential occupational exposures to a comprehensive list of chemicals of concern for breast cancer in a large and diverse workforce.

This paper describes in detail the methods we used to compile and integrate the data underpinning the data visualization tool. First, we identified the most common occupations in which California women are employed. Next, we created and categorized a list of chemicals of concern for breast cancer. We evaluated the probability of on-the-job exposure to chemical categories for each occupation using a job-exposure matrix (JEM). Throughout the process, we worked with an Advisory Committee (https://www.cdph.ca.gov/Programs/CCDPHP/DEODC/OHB/Pages/WORC.aspx) to fill knowledge gaps, and with their help, we defined a set of occupations deemed likely to have large numbers of informal workers. Finally, we developed the data visualization tool, which can be accessed at https://www.cbcrp.org/worker-exposure/

Methods

Characterizing California Women's Employment

We reviewed several potential sources of information to best characterize employment patterns among California women. The most accurate and comprehensive source of these data is the most recent five-year data set from the American Community Survey (ACS, 2010–2014), an ongoing, mandatory, community survey conducted by the U.S. Census Bureau. The household response rate ranged from 89.9 to 97.6 percent during these survey years,[34] with some variations in data quality by demographic and geographic characteristics.[35] The data were obtained via the ACS Public Use Microdata Sample data files for California.[36] This data set includes a sample representing all working and nonworking people ages sixteen or older in California for the years 2010–2014 and includes demographic characteristics including race, Hispanic ethnicity, and age. Each respondent's description of their occupation was coded by census staff using the Census Occupation Code[37] as well as a code or partial code from the 2010 Standard Occupational Classification (SOC) system.[37,38]

We prioritized the occupation groups defined by Census Occupation Codes that employed the largest numbers of women by sorting all of the occupation codes listed in the ACS data by the number of women employed and by selecting the most common occupation groups that accounted for 80 percent of women workers in California. In order to include occupations from the remaining occupation groups that employ fewer women, but which may have elevated exposures to chemicals of concern for breast cancer, all occupation groups with employment of greater than one thousand women were reviewed by three occupational health and cancer experts (RH, PR, and JW) and added to the priority occupations if the reviewers agreed that they were occupations likely to have elevated exposure to chemicals of concern.

Informal Workers

We identified nine categories of occupations or industries that are likely to have a large proportion of informal workers, based on input from our Advisory Committee and experts working in the field, our own experience working in occupational health, and published literature.[20,21,23,39,40] These are domestic workers, restaurant workers, agriculture workers, makeup artists and hairdressers, janitors and custodians, day laborers,

garment workers, artists, and street vendors. We linked these nine categories to the corresponding occupation codes in the ACS data set based on the SOC occupation descriptions. We used the number of self-employed workers reported in the ACS data as a proxy measure of the number of informal workers in the data visualization tool. The limitations of this approach are detailed in the discussion.

Demographics

According to the standard racial groups defined by ACS, Latinos are an ethnic group and may be of any race. However, many Latinos opt out of the standard racial categories by choosing "Some other race" or, to a lesser extent, by failing to answer the race question altogether.[41] In order to present a clear picture of the California female workforce, we are using a modified race and ethnicity categorization, as shown in Table 1. For this categorization, we split out non-Hispanic Whites into their own category, and Hispanic persons (of any race) are also presented as their own category.

Chemicals of Concern Data

We created a combined list of chemicals of concern for breast cancer risk (mammary gland carcinogens, endocrine disruptors, and mammary gland developmental toxicants). We identified the following data sources as the most relevant, complete, and timely: the Silent Spring Institute Mammary Carcinogens Review Database,[6] the TEDX list of endocrine-disrupting chemicals (EDC),[42] and the list of mammary gland developmental toxicants identified by Rudel et al.[7] After excluding duplicates, chemicals with no history of commercial production, and nonchemical agents, we identified 1012 chemicals: 850 EDCs, 173 mammary gland carcinogens, and 108 developmental toxicants (chemicals may be of more than one type). The categories of chemicals of concern and their overlap are shown in Figure 1.

An industrial hygienist and an occupational epidemiologist (JW and SB) grouped chemicals on the basis of chemical properties and/or usage characteristics into twenty-five categories (see Appendix). Category definitions were designed to be relevant to occupational exposure circumstances, have enough detail to provide useful information on exposures, and to be feasible to assess exposure to each of the categories among all of the occupations included in the JEM. Information on chemical characteristics and use was obtained from National Toxicology Program reports on carcinogens,[43] PubChem (a database of chemical profiles maintained by the National Center for Biotechnology Information of the National Library of Medicine),[44] the Hazardous Substances Data Bank (also maintained by the National Library of Medicine),[45] web searches, and the expert knowledge of study personnel. We created variables to indicate chemicals as EDCs, mammary gland carcinogens, and/or mammary gland developmental toxicants. We also created variables to indicate chemicals listed by the U.S. Environmental Protection Agency as high production volume chemicals,[46] as well as chemicals which have been sampled in workplaces by the U.S. Occupational Safety and Health Administration (as listed in their Chemical Exposure Health Database years 2003–2015).[47] Note that chemicals may be present in more than one category, with

Table 1. Numbers of California Working Women Aged 16 or Older by Race/Ethnicity and Age in American Community Survey, 2010–2014.

	N	%
Total number of workers	7,774,697	
Total workers by race/ethnicity		
Asian	1,225,307	15.8
Black	447,856	5.8
Hispanic	2,428,738	31.2
Native American	51,256	0.7
Pacific Islander	31,738	0.4
White, not Hispanic	3,299,739	42.4
Other race	290,063	3.7
Total workers by age		
16–19	214,462	2.8
20–29	1,708,499	22.0
30–39	1,712,137	22.0
40–49	1,759,550	22.6
50–59	1,593,986	20.5
60–64	471,153	6.1
65+	314,910	4.1

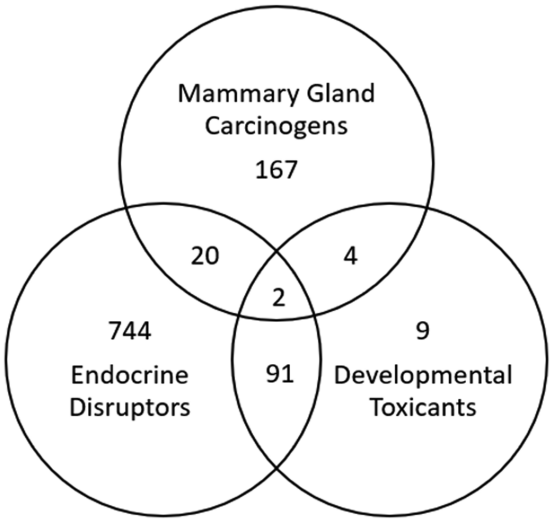

Figure 1. Overlap between input data sets.

the exceptions of dioxins, phthalates, parabens, and alkylphenols.

Creation of Job-Exposure Matrices

We created a JEM to assess potential for exposure to chemicals of concern by occupational group among the selected ACS occupational groups. Rating and decision-making methods were similar to those used in the creation of other JEMs.[29,31,32,48,49] Two industrial hygienists (JW and JC) assessed the potential for exposure for each combination of occupation and chemical category. They were blinded to one another's ratings, and a board-certified occupational medicine physician (RH) acted as a tiebreaker where their scores disagreed.

Each combination of occupation and exposure category was denoted as having probable, possible, or unlikely exposure (described in more detail below) based on professional knowledge of industrial processes, chemical use, and job tasks as well as data sources including product databases, safety data sheets, and published literature. The 2010 SOC Manual was the source for basic descriptions of tasks and examples of jobs within occupational categories.[38] For occupations identified as likely to informally employ large numbers of women, a separate assessment was made for informal work taking into consideration differences in exposures that are likely to be seen in an informal job versus formal employment. In some chemical groups, there are chemicals that are no longer in use and past use or prior presence in a product was included in the assessment. Consistent with the approach of similar published research, we grouped by occupation only without further breakdown by industry.[29,32,49] The exposure designations reflect the probability that an occupation has—or in the case of chemicals no longer in use, had in the past—exposures that exceed background levels (i.e., in excess of levels of chemicals that occur in virtually all workplaces, such as cleaning products). These are the exposure designations:

Probable. Women working in this occupation have or had a high probability of exposure at work to one or more chemicals of concern for breast cancer through direct use of these chemicals or from working in an area where these chemicals are being used or produced.

Possible. Women working in this occupation may or may not have been exposed at work to one or more chemicals in this category. This designation is assigned in the following circumstances: there is enough variability in the agent group that products may or may not have any of the listed agents as ingredients; not all workplaces use the practices that may lead to exposure; a wide variety of individual job titles with varying exposures are included in a given occupation category; or the occupational group is found in a wide variety of industries.

Unlikely. Women working in this occupation are not likely to be exposed at work to any chemicals in this category, or their exposure is not expected to be any greater than that of the general population.

Data Visualization Tool

We developed an interactive online data visualization tool in collaboration with Periscopic, a commercial data visualization firm in Portland, Oregon, to allow users to visualize the data we gathered about women workers and categories of chemicals of concern. The tool was launched in July 2018.

Results

Table 1 shows the 7,774,697 California working women ages sixteen or older in the ACS 2010–2014 data, broken down by race/ethnicity and age. The most common race and ethnicity reported was non-Hispanic White (42.4%) followed by Hispanic of any race (31.2%). Of the nearly five hundred occupational groups represented in the ACS data, 80 percent of women workers were captured by the ninety-one most common groups. An additional fifty-four less-common groups with potentially elevated exposure to chemicals of concern were added to the JEM based on expert review, for a total of 145 groups representing 85 percent of women workers. There are approximately 6.6 million women working in the selected occupations. We also linked the nine descriptive categories of occupations with significant informal employment to forty corresponding occupation groups in the ACS data set (e.g., the advisory committee-identified category "makeup artists and hairdressers" was linked to ACS entries for SOC codes for "Hairdressers, Hairstylists, and Cosmetologists" as well as "Makeup Artists, Theatrical and Performance"); twenty-four occupations overlapped with those identified above, resulting in a total of 161 occupations included in the data visualization tool.

Table 2 shows the ten most common occupations for women working in California, and the SOC code and number of women employed in each, based on the 2010–2014 ACS. Exposure is unassigned for two occupations selected from the ACS data (11-9XXX (Managers, all other) and 11-1021 (General and operations managers)) despite being the ninth and fiftieth most common occupations because a reasonable assessment of exposure could not be made due to the wide range of industries encompassed by these categories.

Overall, fifty-seven (39.9%) occupations investigated had probable exposure to at least one chemical category.

Table 2. The Ten Most Common Occupations for Women Workers in California, 2010–2014.

Occupation description	SOC code	Estimated number of workers (ACS)
Secretaries and administrative assistants	43-6010	310,470
Cashiers	41-2010	282,052
Elementary and middle school teachers	25-2020	252,404
Registered nurses	29-1141	243,053
Retail salespersons	41-2031	220,713
Personal care aides	39-9021	205,666
Maids and housekeeping cleaners	37-2012	197,778
Customer service representatives	43-4051	173,840
Managers, all other[a]	11-9XXX	157,700
Accountants and auditors	13-2011	154,899

Note. ACS = American Community Survey, U.S. Census Bureau; SOC = Standard Occupational Classification (ACS version).
[a]Excluded from the JEM; assessment of exposure could not be made due to the wide range of potential tasks and industries.

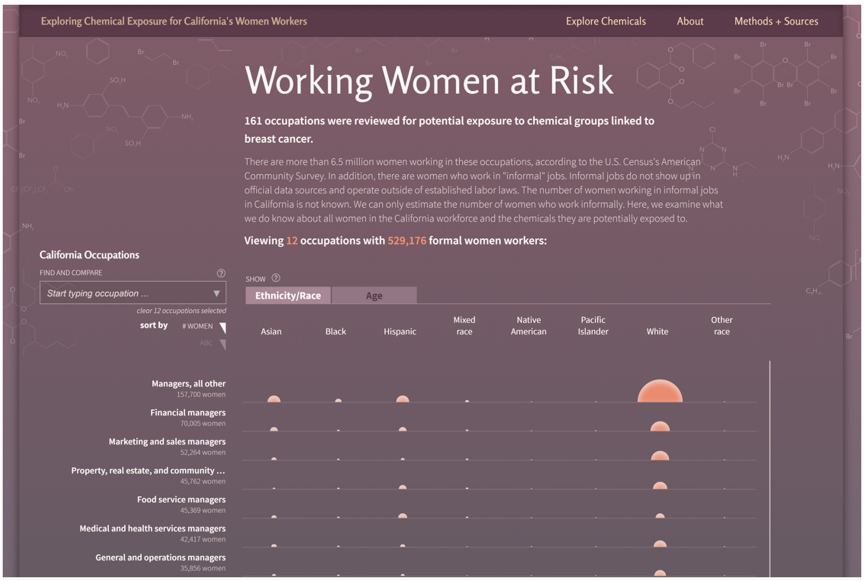

Figure 2. Landing page of the data visualization tool. Here, a user has searched for all occupations including the word manager using the search box at left ("California Occupations Find and Compare"). The ticker above the table shows that this search yields 12 occupations with 529,176 formal women workers.

Only twenty-seven (18.9%) occupations representing 1,479,862 (22.4%) women had unlikely exposure to all twenty-five categories, with the remaining 81.1 percent of job titles representing the remaining 77.6 percent of women having possible or probable exposure to one or more category of concern for breast cancer. We assessed exposure in each of 3575 cells in the JEM. Probable exposure was assigned to 156 (4.4%) job-chemical category pairings, possible to 817 (22.9%) pairings, and unlikely to 2602 pairings (72.8%). Phthalate exposure was the most common, with twenty-six (18.2%) occupations assigned probable exposure and seventy-eight (54.5%) assigned possible exposure.

All occupations included are shown on the landing page of the data visualization tool. Figure 2 shows the landing page after a user has searched for all occupations including the word "manager." Users can toggle between Ethnicity/Race and Age on top to view results by occupation in salmon- or blue-colored semicircles, respectively. The size of the colored semicircle is proportional to the number of women in that category. Users can sort on categories listed for Ethnicity/Race and Age groups by clicking on that header at top and can also sort alphabetically or by total number of women at left.

Figure 3 shows occupation overlay for Maids and Housekeeping Cleaners. There is also data in the informal tab, indicating that our assessment showed this was one of the forty ACS occupation groups deemed likely to employ substantial numbers of informal workers. The Ethnicity/Race and Age breakdown for formally

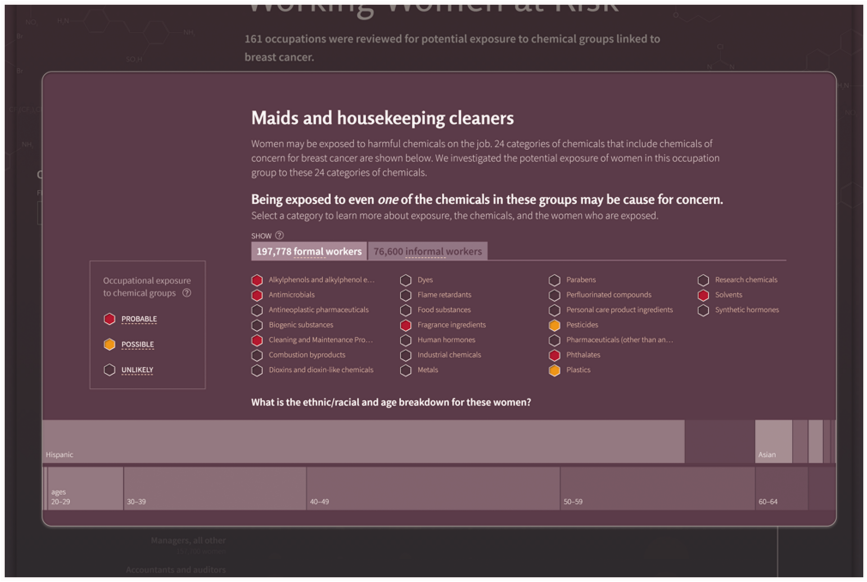

Figure 3. Occupation overlay for Maids and Housekeeping Cleaners.

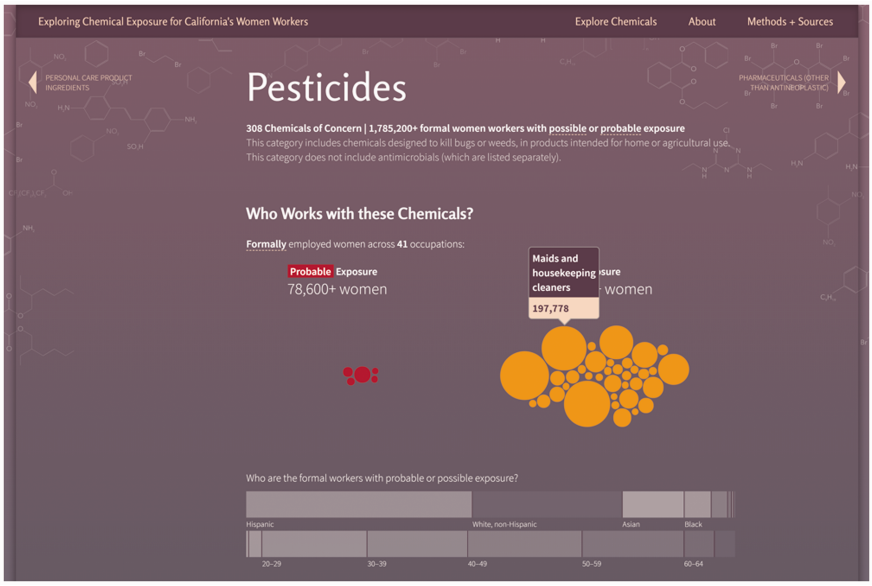

Figure 4. Chemicals landing page for Pesticides category of chemicals of concern for breast cancer. Here, a user has hovered the mouse over the scaled bubble representing possible exposure to pesticides, generating a pop-up with the count of 197,778 Maids and Housekeeping Cleaners.

employed women in this occupation is shown at the bottom of the overlay. The overlay shows a tool tip describing "308 chemicals" hovering over the Pesticides category; clicking there leads to a landing page for the chemical category (Figure 4), which includes the estimated number of women with probable or possible exposure to each, with scaled bubbles representing all occupations with probable or possible pesticide exposure by number of workers. Below this, the Ethnicity/Race and Age breakdown of workers exposed to these chemicals is shown as well as the full list of chemicals included in the category (not shown).

Discussion

We used the best available sources of data on women's employment in California and chemicals of concern for breast cancer to create a JEM and an interactive data

visualization tool, providing information on potential exposures to these chemicals and demographics for the 85 percent of California working women included in the analysis. The tool allows users to explore potential occupational exposures to a broad list of chemicals of concern for breast cancer among approximately 6.6 million women. Women in informal jobs have been included in the analysis and visualization, providing information on this vulnerable and often overlooked group. To our knowledge, this tool is the first of its kind to provide broad snapshots of the chemical exposure risks posed to California working women.

This endeavor also revealed significant data gaps. Notably, we found few relevant data sources, all of which had significant limitations. The ACS data set does not include occupation data on the 43 percent of women age sixteen and over who are described as "not in labor force" or the 6 percent who are described as unemployed, and some of these women may have had occupational exposures to chemicals of concern in the past. Furthermore, we have assumed that the ACS data provide a representative sample of California women, but it is likely that some women may be missing from the ACS sampling frame because they lack a permanent home address or have chosen not to respond to the survey, and it is likely that these women differ systematically from survey respondents.

Estimating the number of women employed in the informal workforce is impeded by a lack of systematically collected data on informal workers by government agencies. Nonetheless, we did attempt to estimate the number of informal workers in California using the ACS data with various proxy measures and comparing them to estimates obtained using other methods.[39] We used the number of self-employed workers reported in the ACS data as a proxy measure of the number of informal workers in the data visualization tool. Other researchers have used similar methodologies; however, the limitations of this method have been widely described and the use of self-employment as a proxy for informal activity also captures formal behavior, such as entrepreneurial and start-up activities.[21–23] The true number of informal workers may be higher or lower than the estimate provided. Despite our best efforts with proxy measures, reliable estimates of informal employment in California are unavailable, and to fully characterize the informal workforce, better data are required. Workers in illegal industries are also not represented, though these jobs may pose harmful chemical exposures (e.g., clandestine drug synthesis).

We created the chemicals of concern list based on the most relevant and detailed existing sources of data, but we were unable to identify a source of comprehensive, systematically collected data on occupational chemical exposure. While there are some databases with assessments of chemical exposures for a broad range of occupations and chemicals, they are out-of-date[50] or are limited to measurements taken for specific compounds in response to targeted regulatory inspections[47] and therefore cannot be considered representative of exposures broadly encountered by today's female workforce. Furthermore, there are no occupational exposure limits set in California or the United States for the majority of the chemicals of concern for breast cancer. Despite the progressive regulatory environment in California (e.g., the Cleaning Product Right to Know Act,[51] the California Safe Cosmetics Act[52]), the ability to compare occupational exposures with other locations is limited by the same lack of systematically collected quantitative data that we identified as a shortcoming of the existing data in general. Our list includes chemicals that are no longer in use (e.g., pesticides that have been banned for use in the United States) alongside chemicals with current occupational exposure. While this may be seen as a limitation, there are important windows of susceptibility for development of breast cancer that occur at different life stages during periods of breast tissue developmental change (pubertal, pregnancy, etc.), so it is possible that past occupational chemical exposures may still be relevant to more recent breast cancer cases.[53] We also elected to include all EDCs listed by TEDX. The mechanisms of EDCs are often poorly understood, and while some are thought to be specific to breast carcinogenesis, there also is evidence that endocrine disruption of other body systems (e.g., thyroid hormones) may be associated with breast cancer risk.[54]

We selected a qualitative design for exposure classifications based on probabilities of exposure rather than actual exposure levels due to the overall lack of data on exposure levels in workplaces to the chemicals of concern. The underlying JEM is based on the knowledge of subject area experts supplemented by their assessment of relevant literature and other data resources. However, this may be imperfect, with some jobs, tasks, and processes being less familiar than others to the expert. Whether or not a worker at any given work site is actually exposed to an agent depends on many factors, including engineering controls (ventilation, control booths), administrative controls (scheduling, policies, work practices), and personal protective equipment (respirators, gloves, chemical-resistant clothing). Probable exposures may occur where the worker is not engaged in the specific task that creates the exposure but is likely exposed by being in the vicinity of the task.

In order to keep the JEM and data visualization tool to a manageable size, several important areas could not be investigated more fully. First, we combined more than one thousand chemicals into groups by properties and usage. This does not allow for assessment of any individual chemical; however, occupational use of

chemicals is generally by class rather than by specific chemical and the nature of our approach was to assign the probability that a given group of workers was exposed to a given class or type of chemical. By basing our JEM on the most common occupations, rather than industries, we include primarily the retail trade and service industries as they employ the largest numbers of women. While women are employed in industries such as manufacturing, they represent relatively few women workers and chemical exposures are better characterized in many of these industries. In contrast, chemical exposures are poorly understood in the most common jobs for women, providing an opportunity for this tool to lay groundwork for more research on these occupations. While some codes designate a single clearly-defined occupation, others cover a range of workers (e.g., Artists and Related Workers includes painters, welders, ceramic artists, tattoo artists, and 3-D animators) or multiple industries. Some occupations that may be of interest to users are not easy to identify in this tool due to the structure and wording of the SOC group titles, which are created by the U.S. Office of Management and Budget. For example, manicurists are included in the broad occupation group "Miscellaneous personal appearance workers." And finally, our focus on occupation precluded consideration of the additional exposure risks from many of these chemicals as part of everyday living.

Since all of the existing data resources lack at least one key data element, policy efforts to expand existing data collection programs are critical to advancing the research agenda. An overarching limitation is that few chemicals have been assessed for carcinogenicity and even fewer for breast cancer risk. Ongoing reforms to chemical safety testing policies and investment in testing programs and technologies are necessary to begin characterizing the risks associated with a meaningful fraction of the chemicals in commerce. Enhancement and expansion of existing federal and state tracking systems such as population-based surveys (e.g., Behavioral Risk Factor Surveillance System, California Health Interview Survey) and cancer surveillance systems (e.g., California Cancer Registry or Surveillance, Epidemiology, and End Results Program) could be promoted by advocacy efforts. Adding detailed occupation and industry and other job information or even biomonitoring components to population-based surveys as well as improving the accuracy and completeness of occupation and industry in cancer surveillance systems would allow researchers to characterize women's employment and chemical exposures with more detail to inform the role of workplace risk factors for disease. Other more resource-intensive opportunities for gathering detailed chemical exposure data would be to expand the California Biomonitoring Program (or similar programs) to include more occupational cohorts and development of new systematic workplace chemical monitoring programs for targeted occupations of concern for breast cancer risk.

In its National Occupational Research Agenda for Cancer, Reproductive, Cardiovascular, and Other Chronic Disease Prevention Report, the National Institute for Occupational Safety and Health identified the need for enhanced data collection on employment as well as exposure to potentially carcinogenic chemicals as a critical objective toward the prevention of occupationally-related cancer.[55] Mirroring some of our own conclusions, this report specifically calls for improvements in the reporting of occupational information in existing cancer surveillance systems and notes the value of a nationally representative occupational exposure survey to collect data on exposure agents in the workplace. Given the current data gaps, research efforts must be accompanied by advocacy efforts to enhance surveillance programs in order to fully understand the potential role of workplace chemical exposures in breast cancer risk.

Conclusion

The data visualization tool is designed to be a useful informational tool for workers and worker advocates. It can serve as a launching point for researchers to identify areas of exposures to chemicals of concern and/or breast cancer risk that should be explored and to highlight areas that would benefit from intervention or advocacy activities. Based on our experience creating this tool, we have identified a number of areas in which policy efforts to prevent occupational exposures to chemicals of concern for breast cancer could be expanded or improved, with enhanced collection of data on women's employment and occupational exposure to chemicals of concern for breast cancer being the most critical needs. While each source of data used in the analysis had notable shortcomings, we were able to create a data visualization tool that allows users to explore exposure to chemicals of concern for breast cancer among the majority of California working women.

Appendix. Categories of Chemicals of Concern, Category Descriptions and Examples, and Count of Chemicals per Category.

Category	Category criteria	Examples	Number of chemicals in category[a]
Alkylphenols and alkylphenol ethoxylates	A class of related chemicals that are used as detergents, surfactants, and lubricants in industrial processes and in industrial cleaning products. No longer permitted for use in household products in California but still present in industrial detergents.	4-nonylphenol, 4-dodecylphenol, 4-octylphenol	15
Antimicrobials	Substances that suppress the growth of harmful microorganisms such as bacteria, viruses, or fungi on inanimate objects and surfaces. This category excludes crop and household pesticides (see Pesticides category).	Resorcinol, glutaraldehyde, Triclosan	32
Biogenic substances	Substances which are produced by living organisms.	Daidzein, estrogen, ochratoxin	59
Cleaning and maintenance products	Chemical ingredients in household products such as cleaning products, adhesives, paints, and air fresheners. Phthalates and parabens are household product ingredients which are listed in separate categories.	Amsonic acid, toluene	31
Combustion products	Substances created when materials (fuels, plant materials, waste) are burned. Some agents in this category are also components of petroleum fuels.	Benzene, environmental tobacco smoke, benzo [a]pyrene	62
Dioxins and dioxin-like chemicals	Dioxins and chemicals with similar properties to dioxins (polychlorinated and polybrominated biphenyls, polychlorinated dibenzofurans) were once used as flame retardants, coolants, and lubricants. No longer produced intentionally but present as by-products or contaminants and may be produced during combustion of certain materials.	2,3,7,8-tetrachlorodibenzo-p-dioxin, Aroclor 1260, 4-chlorobiphenyl	121
Dyes	Dyes (for textiles, food, and other products) and chemicals used to produce dyes.	Nitrobenzene, malachite green, FD&C Violet No. 1	34
Flame retardants	Substances that are added or applied to materials in order to slow or prevent the growth of fire. Dioxin-like chemicals formerly used as flame retardants are listed in the "dioxins and dioxin-like chemicals" category.	Polybrominated diphenyl ethers (PBDEs), boric acid, 2,2',6,6'-tetrabromobisphenol A (TBBPA)	52
Food constituents and additives	Substances naturally occurring in foodstuffs, occurring as a result of food preparation, and food additives.	FD&C Yellow No. 6, acrylamide, quercetin	53
Fragrance ingredients	Identifies chemicals that are used in fragrances (includes perfume compounds as well as solvents and fixatives for fragrances).	Galaxolide, benzaldehyde, diethyl phthalate	62
Human endogenous hormones	Hormones endogenous to humans.	Progesterone, testosterone	7
Industrial chemicals	Substances used as reactants, ingredients, or processing aids in industrial manufacturing processes.	Sodium sulfide, urethane	186

(continued)

Continued.

Category	Category criteria	Examples	Number of chemicals in category[a]
Metals	Metals, metalloids, and organometallic compounds.	Lead, indium phosphide, tributyltin	27
Nonhuman hormones	Hormones not endogenous to humans (includes hormones endogenous to nonhuman animals).	Mestranol, conjugated estrogens	14
Other	Several chemicals that do not fall into another category.	Trinitrotoluene, ammonium nitrate	6
Parabens	A class of related chemicals which are used as preservatives in cosmetics, personal care products, pharmaceuticals, and foods.	Methylparaben, propylparaben, butylparaben	12
Perfluorinated compounds	Perfluoroalkyl chemicals used in nonstick, stain-repellent, and waterproof coatings.	Perfluorooctanoic acid (PFOA), perfluorooctanesulfonic (PFOS)	13
Personal care products	Substances used in cosmetics and personal care products (parabens and phthalates listed separately).	Decamethylcyclopentasiloxane (D5), musk xylene, dadzein	78
Pesticides	Crop and household pesticides and herbicides (antimicrobials listed separately)	Imidacloprid, mirex, glyphosate	308
Pharmaceuticals—antineoplastic	Antineoplastic and cytotoxic pharmaceuticals.	Amsacrine, tamoxifen	21
Pharmaceuticals—other	Pharmaceuticals other than antineoplastics, as well as chemicals used to synthesize pharmaceuticals.	Clotrimazole, indomethacin	57
Phthalates	A group of related chemicals used in many products to make plastics flexible and as solvents. Examples of use include: vinyl flooring, plastics in automobiles, plastic clothing, perfumes, and nail polish.	Diisononyl phthalate, di(2-ethylhexyl)phthalate, dibutyl phthalate	16
Plastics	Chemicals and additives used to make plastics as well as well as contaminants found in plastics (phthalates listed separately).	Bisphenol A, benzophenone, toluene	61
Research chemicals	Chemicals used in research, such as laboratory reagents, stains, and tumor inducers.	Phenolphthalein, 7,12-dimethylbenz[a]anthracene (DMBA), alizarin	61
Solvents	Organic (carbon-containing) solvents. Examples of use include: paints, adhesives, degreasers, cleaning products, inks.	Xylene, methyl ethyl ketone, dimethylformamide	31

Note. [a]Chemicals may be present in more than one category.

Acknowledgments

We thank the Women's Occupations and Risk from Chemicals (WORC) Project Advisory Committee for their invaluable input on the project: Gail Bateson (formerly of Worksafe), Lisa Fu and Julia Liou (California Healthy Nail Salon Collaborative/Asian Health Services), Catherine Porter (California Healthy Nail Salon Collaborative), Janette Robinson Flint (Black Women for Wellness), Laura Stock (Labor Occupational Health Program at University of California, Berkeley), and Mila Thomas (formerly of SEIU Local 1021).

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This research was supported by funds from the California Breast Cancer Research Grants Program Office of the University of California, Grant Number 21ZB-0901.

ORCID iD

Stella Beckman https://orcid.org/0000-0002-7483-6973

References

1. California Breast Cancer Research Program. *Identifying gaps in breast cancer research: addressing disparities and the roles of the physical and social environment*. San Francisco, CA: University of California, Office of the President, 2007.

2. U.S. Bureau of Labor Statistics. Labor Force Statistics from the Current Population Survey, https://www.bls.gov/cps/cpsaat09.htm (2018, accessed 23 October 2018).
3. Zahm SH and Blair A. Occupational cancer among women: where have we been and where are we going? *Am J Ind Med* 2003; 44: 565–575.
4. Hohenadel K, Raj P, Demers PA, et al. The inclusion of women in studies of occupational cancer: a review of the epidemiologic literature from 1991–2009. *Am J Ind Med* 2015; 58: 276–281.
5. U.S. Government Accountability Office. *Toxic substances: EPA has increased efforts to assess and control chemicals but could strengthen its approach*. Washington: GAO, 2013.
6. Rudel RA, Attfield KR, Schifano JN, et al. Chemicals causing mammary gland tumors in animals signal new directions for epidemiology, chemicals testing, and risk assessment for breast cancer prevention. *Cancer* 2007; 109: 2635–2666.
7. Rudel RA, Fenton SE, Ackerman JM, et al. Environmental exposures and mammary gland development: state of the science, public health implications, and research recommendations. *Environ Health Perspect* 2011; 119: 1053–1061.
8. Fenton SE. Endocrine-disrupting compounds and mammary gland development: early exposure and later life consequences. *Endocrinology* 2006; 147: S18–S24.
9. Vandenberg LN, Colborn T, Hayes TB, et al. Hormones and endocrine-disrupting chemicals: low-dose effects and nonmonotonic dose responses. *Endocr Rev* 2012; 33: 378–455.
10. Blair A, Zahm SH and Silverman DT. Occupational cancer among women: research status and methodologic considerations. *Am J Ind Med* 1999; 36: 6–17.
11. Breast Cancer and Occupation: The Need for Action: APHA Policy Statement Number 20146, Issued November 18, 2014. *New Solut* 2015;25(2):242–252.
12. Engel CL, Sharima Rasanayagam M, Gray JM, et al. Work and female breast cancer: the state of the evidence, 2002–2017. *New Solut* 2018; 28: 55–78.
13. Goldberg MS and Labreche F. Occupational risk factors for female breast cancer: a review. *Occup Environ Med* 1996; 53: 145–156.
14. Snedeker SM. Chemical exposures in the workplace: effect on breast cancer risk among women. *AAOHN J* 2006; 54: 270–279; quiz 280-271.
15. Hansen J. Breast cancer risk among relatively young women employed in solvent-using industries. *Am J Ind Med* 1999; 36: 43–47.
16. Mills PK and Yang R. Breast cancer risk in Hispanic agricultural workers in California. *Int J Occup Environ Health* 2005; 11: 123–131.
17. Villeneuve S, Fevotte J, Anger A, et al. Breast cancer risk by occupation and industry: analysis of the CECILE study, a population-based case-control study in France. *Am J Ind Med* 2011; 54: 499–509.
18. Brophy JT, Keith MM, Watterson A, et al. Breast cancer risk in relation to occupations with exposure to carcinogens and endocrine disruptors: a Canadian case-control study. *Environ Health* 2012; 11: 87.
19. DeMatteo R, Keith MM, Brophy JT, et al. Chemical exposures of women workers in the plastics industry with particular reference to breast cancer and reproductive hazards. *New Solut* 2012; 22: 427–448.
20. Theodore N, Gutelius B and Burnham L. *Home truths: domestic workers in California*. New York: National Domestic Workers Alliance, 2013.
21. International Labour Organisation. *Measuring informality: a statistical manual on the informal sector and informal employment*. Geneva: International Labour Office, 2013.
22. Alderslade J, Talmage J and Freeman Y. *Measuring the informal economy - one neighborhood at a time*. Washington: Brookings, 2006.
23. Andrews D, Sánchez A and Johansson Å. *Towards a better understanding of the informal economy*. Paris: OECD, 2011.
24. Kauppinen T, Uuksulainen S, Saalo A, et al. Use of the Finnish Information System on Occupational Exposure (FINJEM) in epidemiologic, surveillance, and other applications. *Ann Occup Hyg* 2014; 58: 380–396.
25. Peters CE, Ge CB, Hall AL, et al. CAREX Canada: an enhanced model for assessing occupational carcinogen exposure. *Occup Environ Med* 2015; 72: 64–71.
26. Siemiatycki J and Lavoue J. Availability of a New Job-Exposure Matrix (CANJEM) for epidemiologic and occupational medicine purposes. *J Occup Environ Med* 2018; 60: e324–e328.
27. Kauppinen T, Toikkanen J, Pedersen D, et al. Occupational exposure to carcinogens in the European Union. *Occup Environ Med* 2000; 57: 10–18.
28. Acheampong T, Yuan JM, Koh WP, et al. Occupational exposure to endocrine disrupting substances and the risk of breast cancer: the Singapore Chinese health study. *BMC Public Health* 2018; 18: 929.
29. Brouwers MM, van Tongeren M, Hirst AA, et al. Occupational exposure to potential endocrine disruptors: further development of a job exposure matrix. *Occup Environ Med* 2009; 66: 607–614.
30. Cantor KP, Stewart PA, Brinton LA, et al. Occupational exposures and female breast cancer mortality in the United States. *J Occup Environ Med* 1995; 37: 336–348.
31. Petralia SA, Vena JE, Freudenheim JL, et al. Risk of premenopausal breast cancer in association with occupational exposure to polycyclic aromatic hydrocarbons and benzene. *Scand J Work Environ Health* 1999; 25: 215–221.
32. Van Tongeren M, Nieuwenhuijsen MJ, Gardiner K, et al. A job-exposure matrix for potential endocrine-disrupting chemicals developed for a study into the association between maternal occupational exposure and hypospadias. *Ann Occup Hyg* 2002; 46: 465–477.
33. Vrijheid M, Armstrong B, Dolk H, et al. Risk of hypospadias in relation to maternal occupational exposure to potential endocrine disrupting chemicals. *Occup Environ Med* 2003; 60: 543–550.
34. U.S. Bureau of the Census. American Community Survey: response rates, https://www.census.gov/acs/www/methodology/sample-size-and-data-quality/response-rates/ (accessed 13 April 2021).
35. Spielman SE, Folch D and Nagle N. Patterns and causes of uncertainty in the American Community Survey. *Appl Geogr* 2014; 46: 147–157.

36. U.S. Bureau of the Census. American Community Survey (ACS), five-year Public Use Microdata Sample (PUMS), 2010-2014, http://www2.census.gov/programs-surveys/acs/data/pums/2014/5-Year/csv_pca.zip (accessed 10 June 2016).
37. U.S. Bureau of the Census. *2010-2014 ACS 5-year PUMS Code Lists*, http://www2.census.gov/programs-surveys/acs/tech_docs/pums/code_lists/ACSPUMS2010_2014CodeLists.xls?# (accessed 10 June 2016).
38. Executive Office of the President Office of Management and Budget. *Standard occupational classification manual 2010*. Alexandria, VA: OMB, 2010.
39. Flaming D, Haydamack B and Joassart-Marcelli P. *Hopeful Workers, Marginal Jobs: LA's Off-the-Books Labor Force*, Economic Roundtable Research Report, 2005.
40. Lund F and Naidoo R. The changed world of work. *New Solut* 2016; 26: 145–154.
41. Tafoya S. Latinos and racial identification in California. In H. P. Johnson (Ed.), *California counts: Population trends and profiles* (pp. 1–16). San Francisco: Public Policy Institute of California, 2003.
42. The Endocrine Disruption Exchange Inc. (TEDX). TEDX list of potential endocrine disruptors, https://endocrinedisruption.org/partners-in-science/tools-for-scientists-and-educators (2015, accessed 6 May 2015).
43. NTP (National Toxicology Program). *Report on carcinogens, fourteenth edition*. Research Triangle Park: U.S. Department of Health and Human Services, 2016.
44. Kim SC, Cheng T, Gindulyte A, et al. PubChem 2019 update: improved access to chemical data. *Nucleic Acids Res* 2019; 47: D1102–D1109.
45. U.S. National Library of Medicine. Hazardous Substances Data Bank (HSDB), https://toxnet.nlm.nih.gov/newtoxnet/hsdb.htm (accessed 16 September 2017).
46. EPA: High Production Volume List, https://comptox.epa.gov/dashboard/chemical_lists/EPAHPV (accessed 25 July 2021)
47. U.S. Occupational Safety and Health Administration. Chemical exposure health data, https://www.osha.gov/opengov/healthsamples.html 2016, (accessed 15 August 2016).
48. Lope V, Garcia-Perez J, Perez-Gomez B, et al. Occupational exposures and mammographic density in Spanish women. *Occup Environ Med* 2018; 75: 124–131.
49. Henneberger PK, Kurth LM, Doney B, et al. Development of an asthma-specific job exposure matrix for use in the United States. *Ann Work Expo Health* 2020; 64: 82–95.
50. U.S. National Institute for Occupational Safety and Health. National Occupational Exposure Survey (NOES) (1981–1983), http://www.cdc.gov/noes/default.html (1990, accessed 27 February 2019).
51. California S.B. 258 Cleaning Product Right to Know Act of 2017, 2017.
52. California S.B. 484, California Safe Cosmetics Act of 2005, 2005.
53. Terry MB, Michels KB, Brody JG, et al. Environmental exposures during windows of susceptibility for breast cancer: a framework for prevention research. *Breast Cancer Res* 2019; 21: 96.
54. Turken O, NarIn Y, DemIrbas S, et al. Breast cancer in association with thyroid disorders. *Breast Cancer Res* 2003; 5: R110–R113.
55. National Institute for Occupational Safety and Health, National Occupational Research Agenda (NORA) and Cancer, Reproductive Cardiovascular and Other Chronic Disease Prevention (CRC) Council. National occupational research agenda for Cancer, Reproductive, Cardiovascular, and Other Chronic Disease Prevention (CRC), https://www.cdc.gov/niosh/nora/crosssectors/crc/pdfs/National_Occupational_Research_Agenda_for_CRC_508.pdf (2017, accessed 3 January 2018).

Author Biographies

Stella Beckman, MPH, PhD, an epidemiologist in the Department of Epidemiology and Biostatistics at the University of California San Francisco, received her PhD in Epidemiology from the University of California, Berkeley. Her research interests include understanding the occupational health and safety of marginalized worker populations and occupational epidemiology methods.

Elana Silver is an epidemiologist in Oakland, California and principal consultant at Laurelton Research, which provides public health planning, analysis, and presentation services to clients including biotech companies, community-based organizations, and government agencies. Elana specializes in translating complex information into a form that can be more easily understood.

Justine L. Weinberg, MSEHS, CIH, is a certified industrial hygienist in the Occupational Health Branch, California Department of Public Health. She provides technical guidance regarding evaluating, controlling, and preventing occupational exposures.

Susan Hurley, MPH, an epidemiologist in the Department of Epidemiology and Biostatistics at the University of California San Francisco, received her MPH from the University of California Berkeley. She currently serves as project manager for the Women's Occupations and Risks from Chemicals (WORC) project under which the work for this paper was developed.

Matt Frederick is a programmer with the California Department of Public Health.

Jacqueline Chan, MPH, is an industrial hygienist with the California Department of Public Health, Occupational Health Branch. She received her MPH in Industrial Hygiene from the UCLA School of Public Health and has thirty years of experience in occupational health.

Peggy Reynolds, PhD, MPH, a professor in the Department of Epidemiology and Biostatistics at the University of California San Francisco, received her PhD from the University of California Berkeley. She serves as co-principal investigator for this project along with Dr Harrison.

Robert Harrison, MD, MPH, is a physician who is board certified in both occupational and internal medicine. Dr Harrison practices occupational medicine and has investigated many outbreaks of work-related disease and injury in California, and his research interests are in the collection and analyses of work-related injuries and diseases in California.