WELCOME TO THE TRA 6 LECTURE SERIES
INNOVATION PATHWAYS TO SUSTAINABILITY

UNDERSTANDING SUSTAINABILITY THROUGH MERCURY STORIES: LESSONS FOR DECISION-MAKING FROM A VOLATILE ELEMENT

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Understanding Sustainability through Mercury Stories: Lessons for Decision-Making from a Volatile Element


More info at http://mercurystories.org
Mercury pollution has increased dramatically

Mercury concentrations in Arctic biota as fraction of present-day levels

[AMAP, 2011]

"sufficient evidence of significant adverse impacts on human health and/or the environment from environmental releases of mercury to warrant global political action to address these issues"

[UNEP, 2002]

Entry into force: 2017
In the early 2000s, it was estimated that **more than 300,000 babies** in the US were born every year to women whose mercury levels exceeded the US guidelines intended to protect against adverse neurodevelopmental effects (Mahaffey et al., 2003).
Global mercury emissions, 2015

Global Mercury Assessment, 2018 via US EPA
The legacy of past pollution is still present
Mercury is connected to multiple SDGs

Related Sustainable Development Goals

- **Goal 1** No Poverty
- **Goal 2** Zero Hunger
- **Goal 3** Good Health and Well-Being
- **Goal 6** Clean Water and Sanitation
- **Goal 7** Affordable and Clean Energy
- **Goal 8** Decent Work and Economic Growth
- **Goal 11** Sustainable Cities and Communities
- **Goal 12** Responsible Consumption and Production
- **Goal 14** Life Below Water
- **Goal 15** Life on Land

Questions

1) What information is needed to inform decision-making on mercury?
2) What lessons can be drawn from mercury to inform action on broader sustainability challenges?

Approaches

- Systems analysis
- New modelling techniques
- Policy engagement
- Lessons from case studies
Human-Technical-Environmental Systems

Environment and Ecosystems

Technologies & Infrastructure

People and Communities

Institutions & Knowledge
How to analyze these systems?

**Step 1:** Identify the system components
- Human
- Technical
- Environmental
- Institutional
- Knowledge

**Step 2:** Map material *interactions* between components in a matrix format (in context of non-material components) and identify *pathways*

**Step 3:** Identify *interveners* and interventions (changes in components or interactions)

**Step 4:** Draw insights and lessons

Mercury Stories

Global Human-Technical-Environmental Cycling
Chasing Quicksilver

Part I
Human Health
Mercury’s Caduceus

Part II
Energy, Industry and Pollution
Mercury, Winged Messenger

Mining and Sustainable Livelihoods
Mercury, God of Finance

Assets and Liabilities
Mercury, God of Commerce
Health: “When can we eat the fish?”

The mercury and human health system: System Components

Non-commercial food harvesters and consumers
- National and local laws and regulations
- Dietary recommendations
- Cultural norms
- Minamata Convention

Producers and consumers of commercial market food

Mercury in production processes
- Forms of mercury
- Properties of mercury
- Exposure routes
- Mercury concentrations in people
- Health impacts from mercury exposure

Ecosystems near mercury sources

Ecosystems far from mercury sources
- Fish, shellfish, marine mammals
- Rice
The mercury and human health system: System Components

- Non-commercial food harvesters and consumers
- Producers and consumers of commercial market food
- Mercury in production processes
- Ecosystems near mercury sources
- Ecosystems far from mercury sources
- Fish, shellfish, marine mammals
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- National and local laws and regulations
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- Forms of mercury
- Properties of mercury
- Exposure routes
- Mercury concentrations in people
- Health impacts from mercury exposure
The mercury and human health system: System Interactions

(a) Mercury in production processes \[\rightarrow\] National and Local Laws and regulations \[\rightarrow\] Ecosystems near mercury sources

"Industrial uses of mercury contaminate ecosystems near sources"
Industrial uses of mercury contaminate ecosystems near sources
The mercury and human health system: System Interactions

(a) Mercury in production processes → National and Local Laws and regulations → Ecosystems near mercury sources

"Industrial uses of mercury contaminate ecosystems near sources"

(b) Ecosystems near mercury sources → Forms of mercury → Fish, Shellfish, marine mammals, rice

Ecosystem processes transport mercury and lead to methylmercury production"

(c) Fish, Shellfish, marine mammals, rice → Exposure routes → Health impacts → Non-commercial food harvesters and consumers

"Seafood and rice lead to health damages to consumers"
| Industrial uses of mercury contaminate ecosystems near sources | Seafood and rice lead to health damages to consumers | Ecosystem processes transport mercury and lead to methylmercury production |
The mercury and human health system: Pathways

(a) Industrial uses of mercury contaminate ecosystems near sources

(b) Ecosystem processes transport mercury and lead to methylmercury production

(c) Seafood and rice lead to health damages to consumers

Engineering analysis
Semi-structured interviews
Literature reviews
Scenario development

Environmental modelling

Exposure analysis
Health impact assessment
The mercury and human health system: Pathways

(a) Industrial uses of mercury contaminate ecosystems near sources (2-3)

(b) Ecosystem processes transport mercury and lead to methylmercury production (3-3)

(c) Seafood and rice provide health benefits to consumers (3-1)

Health impacts are shaped by biological and socio-economic factors (1-1)

Non-commercial harvesters and commercial food market producers harvest mercury-containing food from ecosystems (1-3)
The mercury and human health system: Interventions

Regulating Emissions and Releases:
Governments

(a) Industrial uses of mercury contaminate ecosystems near sources (2-3)
(b) Ecosystem processes transport mercury and lead to methylmercury production (3-3)
(c) Seafood and rice lead to methylmercury related damages to consumers (3-1)

Harvest bans: local and national governments
Dietary guidelines: governments, others

Health impacts are shaped by biological and socio-economic factors (1-1)
MIT at Minamata Convention negotiations
January 2013
US Domestic action has regional benefits; benefits of global action more widespread

Amanda Giang, PhD ’17
Engineering Systems, MIT, now Assistant Professor, University of British Columbia

Information about impacts affects legal challenges to US mercury rule

US Supreme Court on the Mercury and Air Toxics Standards: “the quantifiable benefits from the resulting reduction in hazardous-air-pollutant emissions would be $4 to $6 million a year” (Michigan v. EPA, 2015)

Giang and Selin on the Mercury and Air Toxics Standards: would exceed $3.7 billion (in 2005 dollars) per year in lifetime benefits for affected individuals

Mercury and Air Toxics Standards: Response to legal challenge (take 1)

“...the cited Giang and Selin (2016) study found that the monetized mercury benefits from implementation of MATS would exceed $3.7 billion (in 2005 dollars) per year in lifetime benefits for affected individuals and $1.1 billion per year in economy-wide benefits.”

“a consideration of cost does not cause us to change our determination that regulation of hazardous air pollutant (HAP) emissions from coal- and oil-fired EGUs is appropriate and necessary”
Hg exposure has distributional impacts

Deposition has historical and new components

Constant emissions with historical legacy
Constant emissions without historical legacy

Policy delay has differential impacts

Figure 3. Mean percent change in policy impacts due to a near-term (2020–2035) 5-year delayed implementation of a New Policy (NP) scenario. Results are discussed at selected sites with varying impact from emissions sources, focusing on (A) tribal areas of eastern Maine, (B) Ahmedabad, India, (C) Shanghai, China, and (D) an area of the Southern Pacific known for albacore tuna fisheries. This Figure was made using the R package autoimage.64


Helene Angot, postdoc 2017-2018, now at U. Colorado

Nick Hoffman, MIT EAPS B.S. 2018, now grad student at U. Wisconsin
“the EPA finds that it is not “appropriate and necessary” to regulate ... emissions from coal- and oil-fired EGUs”

“the quantified mercury-related benefits would still likely be in the millions of dollars and not substantially more than what was estimated when the rule was finalized.”
Congressional testimony on Hg impacts

May 21, 2019, U.S. House of Representatives

Insights from Mercury and Human Health System

- Mercury’s dangers are determined by its inherent properties as a hazardous substance as well as its interactions with technology and society
  - Environmental processes + cultural factors + dietary choices + recommendations
  - Impacts are global but locally determined
- Implementing transitions toward sustainability is dependent on how harms from mercury to human health are valued
  - Valuation and environmental justice
  - Resistance to change processes through system interactions
  - Harm reduction strategies
- Governance of mercury involves integrating risk reduction strategies from local to global, using various types of interventions.
  - Interventions at different points on causal pathways
  - Incorporating socio-economic factors
Which of the following was NOT a term used by alchemists to refer to mercury?

a) Mother Egg
b) Secret Furnace
c) Venomous Dragon
d) Silver Fox
e) Green Lion
Mercury Stories

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Part II
Governments mandate use of air pollution control devices.

“For new [existing] sources, each Party shall require the use of best available techniques and best environmental practices to control and, where feasible, reduce emissions, as soon as practicable but no later than five [ten] years after the date of entry into force of the Convention for that Party.”
More stringent technology controls reduce emissions for a given energy scenario

Stricter controls reduce deposition locally and globally

[Giang et al., ES&T 2015]
Interaction and interventions: fossil fuel use

International bodies, national and local governments, and industries influence fossil fuel use.
汞特定政策的好处大于短期气候政策的好处

在中国，政策效果并不叠加，存在一些利益权衡上的折衷。

Insights on Energy, Industry and Pollution

• **Incremental actions** to reduce mercury emissions using end-of-pipe technologies have substantial benefits for human well-being
  • Local, near-term as well as longer-term benefits to exposure and health
  • Historical and prospective

• **Interactions between air pollution and energy policies** are physical and societal
  • Not additive
  • Technological approaches create incentives and feedbacks

• **Governance challenges**
  • Technological vs. political feasibility: possible vs. ideal
Selected Insights for Sustainability

- The HTE framework offers an approach for addressing sustainability challenges
  - Connects a toolbox of methods (quantitative and qualitative) to build theories and draw insights that help understand sustainability

→ A need for further linking detailed analysis of empirical examples and interactions (among different sustainability processes and goals) with analytical approaches to draw insights across cases

- Ultimately, informing action on sustainability to improve human well-being today and in the future