Safer Sunscreens
Nature’s Approach to UV Protection

Team players: Amanda, Angela, Sophia, Steven, Tessa

Source: flickr.com
Palau Bans Many Kinds of Sunscreen, Citing Threat to Coral

Hawaii bans sunscreens that harm coral reefs

Coral: Palau to ban sunscreen products to protect reefs
Method - “People against dirty”-wants to do better! Can we find safer alternatives for sunscreen?

Motivation

No dirty ingredients
B corporation
Cradle-to-cradle product design

Beyond the bottle
Beyond the burn: why do we need sunscreen?

- Ultraviolet (UV) radiation causes cellular and DNA damage
- ~90,000 cases of skin cancer annually with 10% mortality rate
- 5 bad sunburns early in life can increase melanoma risk by 80%

How does UV radiation penetrate skin?

**Background**

**Approach**

**Evaluation**

**Conclusions**

**Motivation**

UVC (100-280 nm) is blocked by Earth's atmosphere.

UVB (290-320 nm) causes sunburn, skin cancer, and aging.

UVA (320-400 nm) causes aging, wrinkling, and skin cancer.

UV radiation penetrates the skin, affecting the epidermis, dermis, and hypodermis.

- Epidermis
- Dermis
- Hypodermis

- Aging
- Wrinkling
- Skin cancer
- Sunburn
- Skin cancer
- Aging

- Blocked by Earth's atmosphere
UV radiation causes detrimental effects at the cellular and systemic levels.

- Reactive Oxygen Species (ROS)
  - Indirect DNA Damage
  - Direct DNA Damage
  - Protein Oxidation and Deactivation
  - Lipid Peroxidation
  - Altered Gene Expression and Inflammatory Response

Motivation | Background | Approach | Evaluation | Conclusions
Common active ingredients in your sunscreen

What structural attributes make these ingredients ‘sunscreens’?

- Oxybenzone
- Avobenzone
- Homosalate
- Octinoxate
- Octocrylene
- Octisalate
- Titanium dioxide
- Zinc oxide

Motivation  Background  Approach  Evaluation  Conclusions
Common active ingredients in your sunscreen

- Oxybenzone
- Avobenzone
- Homosalate
- Octinoxate
- Octocrylene
- Octisalate

UV light photons increase energy, promoting the organic molecule into an excited state. This leads to heat as a result of energy dissipation.
Chemical absorbers: more harm than good

**Pros**
- Effective
- SAFETY FIRST
- FDA
- $ (Money)

**Cons**
- Oxybenzone
- Warning symbol
- Persistence

---

Motivation  Background: Chemical Hazards  Approach  Evaluation  Conclusions
Current products are bleaching coral

Image: Healthy fire coral compared with bleached coral - Images taken in Bermuda by Jayne Jenkins of the Catlin Seaview Survey.
Current products are bleaching coral

Image: Healthy fire coral compared with bleached coral - Images taken in Bermuda by Jayne Jenkins of the Catlin Seaview Survey.
Chemical UV blockers damage marine ecosystems in many ways.

1. Endocrine disruption

Figure 2. A symbiotic relationship between corals and Symbiodinium

Okinawa Institute of Science and Technology Graduate University (www.oist.jp)
Chemical UV blockers damage marine ecosystems in many ways

1. Endocrine disruption
2. Decreased coral larvae activity

Figure 2. A symbiotic relationship between corals and Symbiodinium
Chemical UV blockers damage marine ecosystems in many ways

1. Endocrine disruption
2. Decreased coral larvae activity
3. Morphological deformities

(Downs et al., Ecotoxicology, 2016)
Chemical UV blockers damage marine ecosystems in many ways:

1. Endocrine disruption
2. Decreased coral larvae activity
3. Morphological deformities
4. DNA damage

(Downs et al., Ecotoxicology, 2016)
Chemical UV blockers damage marine ecosystems in many ways

1. Endocrine disruption
2. Decreased coral larvae activity
3. Morphological deformities
4. DNA damage
5. Bioaccumulates in fish

https://socratic.org/questions/what-is-bioaccumulation-2
Current chemical UV blockers are known human endocrine disruptors.
Common active ingredients in your sunscreen

- titanium dioxide
- zinc oxide
- oxybenzone
- avobenzone
- homosalate
- octinoxate
- octocrylene
- octisalate

How to mineral blockers work?
Mineral blockers **reflect** UV light

Incorporated into formulations as **nanoparticles** to avoid streaky white appearance of sunscreen

https://inchemistry.acs.org/content/inchemistry/en/atomic-news/sunscreen-science.html
Nanoparticles have multiple points of exposure and environmental release.
Nanoparticles: the pitfall of mineral sunscreens

- Protective coating breaks down
- Biggest threat is ROS generation
- Chemosensitizers - increase toxicity of other chemicals

# Mineral sunscreen hazard assessment: Group I & II endpoints

## Chemical Name | Group I Human | Group II and II* Human
<table>
<thead>
<tr>
<th>Carcinogenicity</th>
<th>Mutagenicity</th>
<th>Reproductive</th>
<th>Developmental</th>
<th>Endocrine Activity</th>
<th>Acute Mammalian</th>
<th>Systemic</th>
<th>Neurotox</th>
<th>Neurotox (&gt;1 exposure)</th>
<th>Skin Sensitization</th>
<th>Respiratory Sensitization</th>
<th>Skin Irritation</th>
<th>Eye Irritation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zinc Oxide</td>
<td>L</td>
<td>M*</td>
<td>L*</td>
<td>L*</td>
<td>DG</td>
<td>L*</td>
<td>L*</td>
<td>H*</td>
<td>DG</td>
<td>DG</td>
<td>L*</td>
<td>H</td>
</tr>
<tr>
<td>Titanium Dioxide</td>
<td>H</td>
<td>-</td>
<td>-</td>
<td>M-L</td>
<td>H-M</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>M</td>
</tr>
</tbody>
</table>

## Key

<table>
<thead>
<tr>
<th>L</th>
<th>M*</th>
<th>M-L</th>
<th>M</th>
<th>H-M</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low hazard</td>
<td>High hazard</td>
<td>Moderate to low hazard</td>
<td>High confidence</td>
<td>High to moderate hazard</td>
</tr>
</tbody>
</table>

## Motivation

Background: Mineral Hazards

Approach

Evaluation

Conclusions
## Mineral sunscreen hazard assessment: Environmental endpoints

<table>
<thead>
<tr>
<th>Chemical Name</th>
<th>Ecotox</th>
<th>Fate</th>
<th>Physical</th>
<th>Mult</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Acute Aquatic</td>
<td>Chronic Aquatic</td>
<td>Terrestrial Ecotox</td>
<td>Persistence</td>
</tr>
<tr>
<td>Zinc Oxide</td>
<td>vH*</td>
<td>vH*</td>
<td>-</td>
<td>vH*</td>
</tr>
<tr>
<td>Titanium Dioxide</td>
<td>-</td>
<td>M</td>
<td>-</td>
<td>Vh-H</td>
</tr>
</tbody>
</table>

### Key

<table>
<thead>
<tr>
<th>Hazard Level</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>Low hazard</td>
</tr>
<tr>
<td>vH</td>
<td>Very high hazard</td>
</tr>
<tr>
<td>M</td>
<td>Moderate hazard</td>
</tr>
<tr>
<td>DG</td>
<td>Data gap</td>
</tr>
<tr>
<td>H</td>
<td>High hazard</td>
</tr>
<tr>
<td>*</td>
<td>High confidence</td>
</tr>
<tr>
<td>Vh-H</td>
<td>Very high to high hazard</td>
</tr>
</tbody>
</table>

---

### Background: Mineral Hazards

- **Motivation**
- **Approach**
- **Evaluation**
- **Conclusions**
Technical Performance Criteria:
How can we identify effective alternatives?

1. Broad Spectrum UV Absorbance
   - UVB
   - UVA

2. Antioxidant Capacity
   - \( \cdot \text{OH} \)
   - \( \text{O}_2^\cdot \)

3. Skin Compatibility
   - \( \text{H}_2\text{O} \)

4. Emollience

Approach: Technical

Evaluation

Conclusions
Broad spectrum UVA/UVB absorbance to prevent cellular damage

Molar extinction coefficient

How strongly a substance absorbs light
Antioxidant additives to eliminate ROS species

- Antioxidants eliminate reactive oxygen species such as $\text{O}_2^\cdot$, $\cdot$OH, and NO$\cdot$
- Skin naturally uses antioxidants obtained from dietary sources to protect against sun damage
- Topically applied antioxidants can be effective protection against sun damage
Skin compatibility: Will a compound be dermally absorbed?

High hydrophobicity:
- Remains on skin, may penetrate skin

High Molecular Weight:
- Little skin penetration

Motivation

Background

Approach: Technical

Evaluation

Conclusions
Emollience provides a smooth on-skin feel

Emollients are derived from petrochemical or natural sources, such as vegetable oils and fats.

Key Structural Components

saturated hydrocarbon

unsaturated hydrocarbon

alcohols

vitamin e
Human & Environmental Health Criteria: Can we find bio-compatible ingredients?

1. Non-Toxic to Humans
2. Non-Toxic to Aquatic Life
3. Biodegradable

Approach: Safety

Motivation  Background  Approach: Safety  Evaluation  Conclusions
### Hazard Assessment

1. Literature review
2. Comparison of structural analogs
3. Health & environmental criteria
   - a. Endocrine disruption
   - b. Safety of related structures
   - c. Environmental fate
   - d. Positive health impacts

### Hazard assessment process

#### Motivation

- **Background**
- **Approach: Safety**
- **Evaluation**
- **Conclusions**

#### Hazard Assessment

<table>
<thead>
<tr>
<th>Chemical Name</th>
<th>Group I Human</th>
<th>Group II and IP Human</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Carcinogenicity</td>
<td>Mutagenicity</td>
</tr>
<tr>
<td>---------------</td>
<td>----------------</td>
<td>--------------</td>
</tr>
<tr>
<td>Carotenoids</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lycopene</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Beta-carotene</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Canthaxanthin</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Xanthophyll</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Squalane</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Squalene</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>MMA's</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mycosporine</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Glycine</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Shinorine</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Antioxidants</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vitamin C</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Vitamin E</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Anthocyanins</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Epigallocatechin Gallate</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Resveratrol</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
Inferences on data gaps cannot replace safety testing

<table>
<thead>
<tr>
<th>Chemical Name</th>
<th>Group I Human</th>
<th>Group II and III Human</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Carcinogenicity</td>
<td>Mutagenicity</td>
</tr>
<tr>
<td>Carotenoids</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lycopene</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beta-carotene</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Canthaxanthin</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Xanthophyll</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Squalane</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Squalene</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MMA's</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mycosporine</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glycine</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shironine</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Antioxidants</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vitamin C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vitamin E</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anthocyanins</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Epigallocatechin Gallate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resveratrol</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Hazard Assessment

1. Literature review
2. Comparison of structural analogs
3. Health & environmental criteria
   a. Endocrine disruption
   b. Safety of related structures
   c. Environmental fate
   d. Positive health impacts
Looking to nature for alternatives: Bio-inspired design, bio-compatible formulation

How do plants protect themselves from UV damage?

Are there UV blocking compounds that exist naturally in aquatic ecosystems?

Can we use plant-derived ingredients with established health benefits?

Motivation  Background  Approach: Safety  Evaluation  Conclusions
How do plants avoid sunburn?

- **Photoreceptors** detect light.
- **Chromoplasts** make and store carotenoids.
- **Chlorophyll** absorbs light energy to convert $\text{CO}_2$, $\text{H}_2\text{O}$ to sugars, $\text{O}_2$. 

**Motivation**

**Background**

**Approach: Inspiration**

**Evaluation**

**Conclusions**
Carotenoid antioxidants quench reactive species

‘Excited state’ chlorophyll damaging to plant cells + can produce other ROSs

Carotenoids quench excited state species to prevent cellular damage

ROSs damaging to plant cells

Stable species no cellular damage

Motivation Background Approach: Inspiration Evaluation Conclusions
Dual-prong approach to prevent acute effects of sunburn and downstream cellular damage

Chlorophyll converts UVA/UVB light energy to sugars

UVA/UVB Absorbers

Plants

Colorless carotenoids

Mycosporine-like amino acids (MAAs)

Bio-derived compounds to absorb UVA/UVB rays and prevent cellular damage
Dual-prong approach to prevent acute effects of sunburn and downstream cellular damage

**Antioxidants-ROS Quenchers**

**Plants**
- Carotenoids quench reactive species
  - Beta carotene
  - Lycopene
  - Lutein

**Sunscren**
- Potent, plant-derived antioxidants to quench reactive species
  - Vitamins
  - Flavonoids

**Motivation**

**Background**

**Approach: Inspiration**

**Evaluation**

**Conclusions**
Carotenoids
Carotenoid biosynthesis

phytoene precursor + phytoene synthase

phytoene desaturase

ζ-carotene desaturase

Carotenoid biosynthesis reactions:
- Phytoene synthase
- Phytoene desaturase
- ζ-carotene desaturase

Carotenoids:
- α-carotene
- β-carotene
- Lutein
- Zeaxanthin
- Lycopene
Colorless carotenoids provide multiple attractive properties

- **Broad UV-absorption** spectrum suggesting effective UVA/UVB absorption
- Do NOT absorb in the visible range
- **Potent antioxidants** protecting cells against further radical damage
- **Ubiquitous in nature**

![Carotenoids](image)

**Evaluation: Carotenoids**
Colorless carotenoids are more effective UVB blockers than oxybenzone.

How much light a chemical absorbs normalized by pathlength and concentration.

Conjugated double bonds promote antioxidant characteristics

UV Radiation → Reactive Oxygen Species → Return to ground state or Oxidized carotenoids

**Pros:**
- Prevents skin damage from free radicals
- Stabilizes other active ingredients

**Cons:**
- Absorbance properties may be altered or lost
- Products of unknown toxicity
Colorless carotenoids are likely to penetrate human skin

Empirically calculated: LogKow, MW

Kp [cm/s]

Permeability Constant

Evaluation: Carotenoids

Motivation  Background  Approach  Evaluation: Carotenoids  Conclusions
Phytoene and phytofluene are structurally similar to natural emollients.

**Triterpenoid Structure**
- Unsaturated (top)
- Saturated (bottom)

**Tetraterpenoid Structure**

**Evaluation: Carotenoids**
Carotenoids are already present in our diets

<table>
<thead>
<tr>
<th>Source</th>
<th>Phytoene (mg/kg fresh weight)</th>
<th>Phytofluene (mg/kg fresh weight)</th>
</tr>
</thead>
<tbody>
<tr>
<td>apricots</td>
<td>2.76</td>
<td>0.95</td>
</tr>
<tr>
<td>carrots</td>
<td>1.34</td>
<td>0.57</td>
</tr>
<tr>
<td>red pepper</td>
<td>1.69</td>
<td>0.51</td>
</tr>
<tr>
<td>grapefruit</td>
<td>1.25</td>
<td>0.51</td>
</tr>
<tr>
<td>tomatoes</td>
<td>1.86</td>
<td>0.82</td>
</tr>
</tbody>
</table>

Colorless carotenoids lack benzophenone group linked to endocrine disruption.
Toxicological analysis of structural “safe” analogs

Motivation

Background

Approach

Evaluation: Carotenoids

Conclusions
Colorless carotenoids should not persist in the environment

Light induced oxidation

Intermediates

Mineralization?

Intermediates are unknown and of unknown aquatic toxicity

Microbial oxidation

Intermediates

Motivation Background Approach Evaluation: Carotenoids Conclusions
Mycosporine-like Amino Acids are UV protectors in marine organisms
MAAs have many beneficial characteristics

- Broad UV-absorption
- Potent antioxidants protecting cells against further radical damage
- Found in aquatic organisms
- Polar - not skin permeable or bioaccumulative
Some MAAs are more effective UV blockers
Comparing antioxidant capacity of MAAs

IC$_{50}$
Concentration (uM) to inhibit 50% of reaction with radical indicator

- **Mycosporine glycine** (from marine lichen *Lichina pygmaea*): 3 uM
- **Asterina-330 + palythine** (from red algae *Gelidium corneum*): 10 uM
- **Vitamin C (control)**: 26 uM
- **Porphyra-334 + shinorine** (from red algae *Porphyra rosengurtii*): 80 uM
- **Shinorine** (from red algae *Ahnfeltiopsis devoniensis*): 100 uM

**Evaluation: MAAs**

- **Motivation**
- **Background**
- **Approach**
- **Evaluation: MAAs**
- **Conclusions**
MAAs are not likely to penetrate skin

Permeability Constant

Motivation

Hydrophilic
Mid-range molecular weight

Evaluation: MAAs
One MAA product has reached the market as a sunscreen.
MAAs are not commonly found commercially.
Antioxidant Additives

Motivation

Approach

Evaluation: Antioxidants

Background

Conclusions

vitamins

flavonoids
Vitamin C protects against UVA-induced cell damage

Quenches free radicals, preventing cellular damage associated with:

- Collagen degradation
- Immunosuppression
- Gene mutations leading to cell death
Vitamin C does not easily penetrate skin

Permeability Constant

<table>
<thead>
<tr>
<th>Conventional UV Blockers</th>
<th>Antioxidants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avobenzene</td>
<td></td>
</tr>
<tr>
<td>Dioxibenzzone</td>
<td></td>
</tr>
<tr>
<td>Homosalate</td>
<td></td>
</tr>
<tr>
<td>Octocrylene</td>
<td></td>
</tr>
<tr>
<td>Octinoxide</td>
<td></td>
</tr>
<tr>
<td>Oxybenzone</td>
<td></td>
</tr>
<tr>
<td>Vitamin C</td>
<td></td>
</tr>
</tbody>
</table>

Kp [cm/s]

Motivation   Background   Approach   Evaluation: Antioxidants   Conclusions
Formulation requirements for topical vitamin C treatment

Water soluble and charged in a neutral formulation.

For optimal dermal absorption:
- **Acidic formulation**: uncharged form of vitamin C more effective at crossing skin barrier
- **Esterified forms**: more fat soluble so better at crossing cell membranes, and more stable

Telang, P.S. Ind Derm J. (2013)
Vitamin E & Vitamin C have synergistic UVA/UVB protection properties

- Vitamin E is a fat soluble antioxidant
- Combination of vitamin E and vitamin C
  - 4-fold protection against burn inflammation
  - Prevents thymine dimer formation, which damages DNA

Vitamin E is easily absorbed into skin

**Permeability Constant**

![Permeability Constant Graph]

**Motivation**

**Background**

**Approach**

**Evaluation: Antioxidants**

**Conclusions**
Plant-derived flavonoids are chemopreventive, could they also be effective in topical formulations?

**Epigallocatechin gallate (EGCG)**


Induces cell death in certain cancer cell lines

**Anthocyanins**


Help body detoxify and excrete carcinogens
Several antioxidants have widespread health benefits

- **flavonoids**: Anti-cancer, antihistamine, antimicrobial
- **β-carotene**: Vision and skin health
- **resveratrol**: Brain health & lower blood pressure
- **isothiocyanates**: Anti-cancer, anti-inflammatory
- **vitamin C**: Immunity, collagen formation, inflammation
Several antioxidants have minimal adverse health effects

**Vitamin E Derivatives**
- High doses increase risk of prostate cancer
- Maximum daily intake LESS than seen for adverse effects
- \( \alpha \)-tocopherol: *in vitro* endocrine disruptor

**Vitamin C**
- Pro-oxidant in presence of heavy metals
- No data for skin or eye irritation

**Flavonoids**
- Pro-oxidant in presence of heavy metals
- Rodent models associated with liver damage
- Toxicological profile is poorly understood
UV-Blocking of alternatives outperforms oxybenzone

Motivation | Background | Approach | Evaluation | Conclusions
Carotenoids may penetrate skin while MAAs may wash off

Permeability Constant

Motivation | Background | Approach | Evaluation | Conclusions
**Proposed Solution 1:** Direct use of alternatives as multipurpose additives

**Functional Use**

### Colorless Carotenoids

- 1. Emollient
- 2. Chemical Stabilizer/Antioxidant
- 3. UV Absorber

### Mycosporine-like Amino Acids

- 1. Chemical Stabilizer/Antioxidant
- 2. Antimicrobial
- 3. UV Absorber

### Antioxidants

- 1. Chemical Stabilizer/Antioxidant
- 2. Skin Conditioner
- 3. Antimicrobial
- 4. Indirect UV Absorber

---

**Motivation**

**Background**

**Approach**

**Evaluation**

**Conclusions**
## Proposed Solution 2 (Long term): Use synthetic variants that improve performance criteria

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Issue</th>
<th>Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colorless Carotenoids</td>
<td>Skin permeability is too high due to high hydrophobicity</td>
<td>Add hydrophilic moieties. Preserve UV-absorbing properties.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>![Chemical structure of colorless carotenoids]</td>
</tr>
<tr>
<td>Mycosporine-like Amino Acids</td>
<td>Will easily wash off of skin due to low hydrophobicity</td>
<td>Replace hydrophilic moieties with hydrophobic groups. Preserve UV-absorbing properties.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>![Chemical structure of mycosporine-like amino acids]</td>
</tr>
</tbody>
</table>
Remaining knowledge gaps

Technical Information
- Rates of dermal absorption of colorless carotenoids?
- Persistence of MAAs on skin?
- Thermal & photo stability of formulations
- Formulation benefits of antioxidants?

Safety Data
- Generally limited toxicological data
- How do colorless carotenoids influence dermal penetration of other ingredients?
- Workplace hazards associated with scale-up manufacturing?

Further Research
- Toxicity testing
- Sourcing of raw materials
- Cost feasibility

Motivation  Background  Approach  Evaluation  Conclusions
Thank you to Method & our Greener Solutions course leaders!

Kaj Johnson
Meg Schwarzman
Billy Hart-Cooper,
David Faulkner
Tom McKeag
& our Greener Solutions Cohort