Hochberg, M. (2020)

Holland America Line, (n.d.)

Lau, A. (2019)

FMS, (n.d.)

Royal Caribbean, (n.d.)

Royal Caribbean, (n.d.)

Sail and Cruise, (n.d.)

The Roadmap Towards Circular Cruise Ships

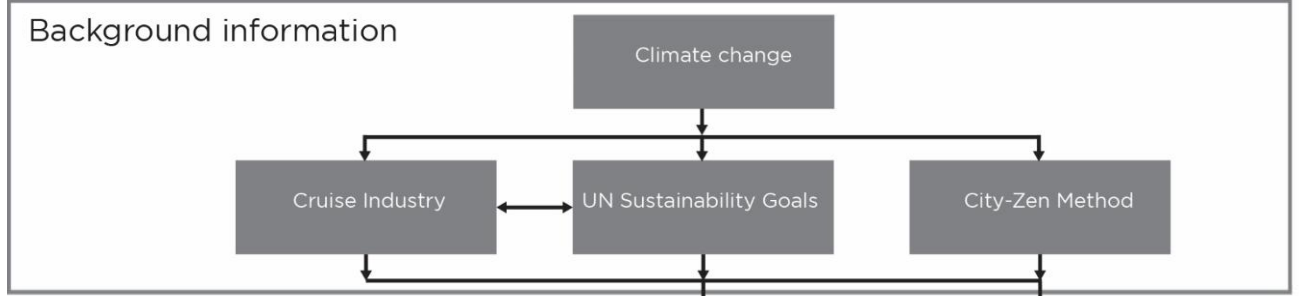
Preventing waste discharge into the environment

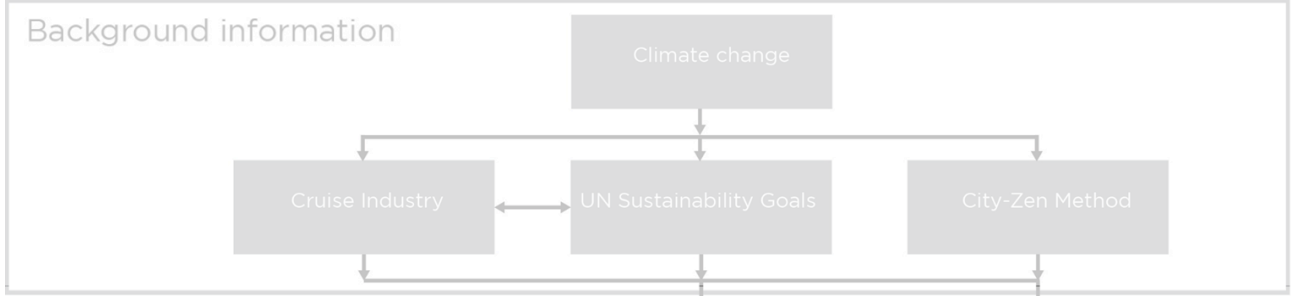
Deirdre van Gameren
08-07-2020

Seastainability

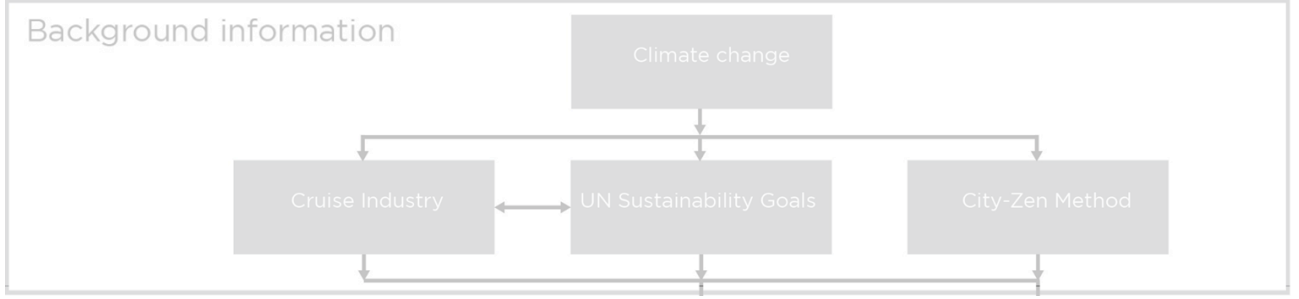
Touchdown, (n.d.)

Background information

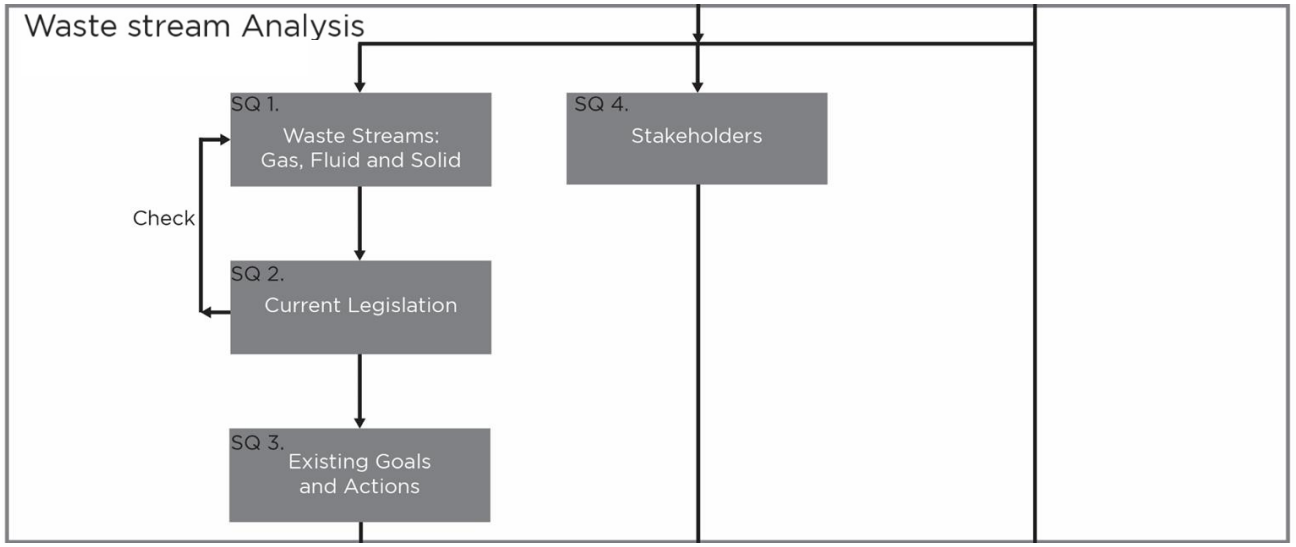


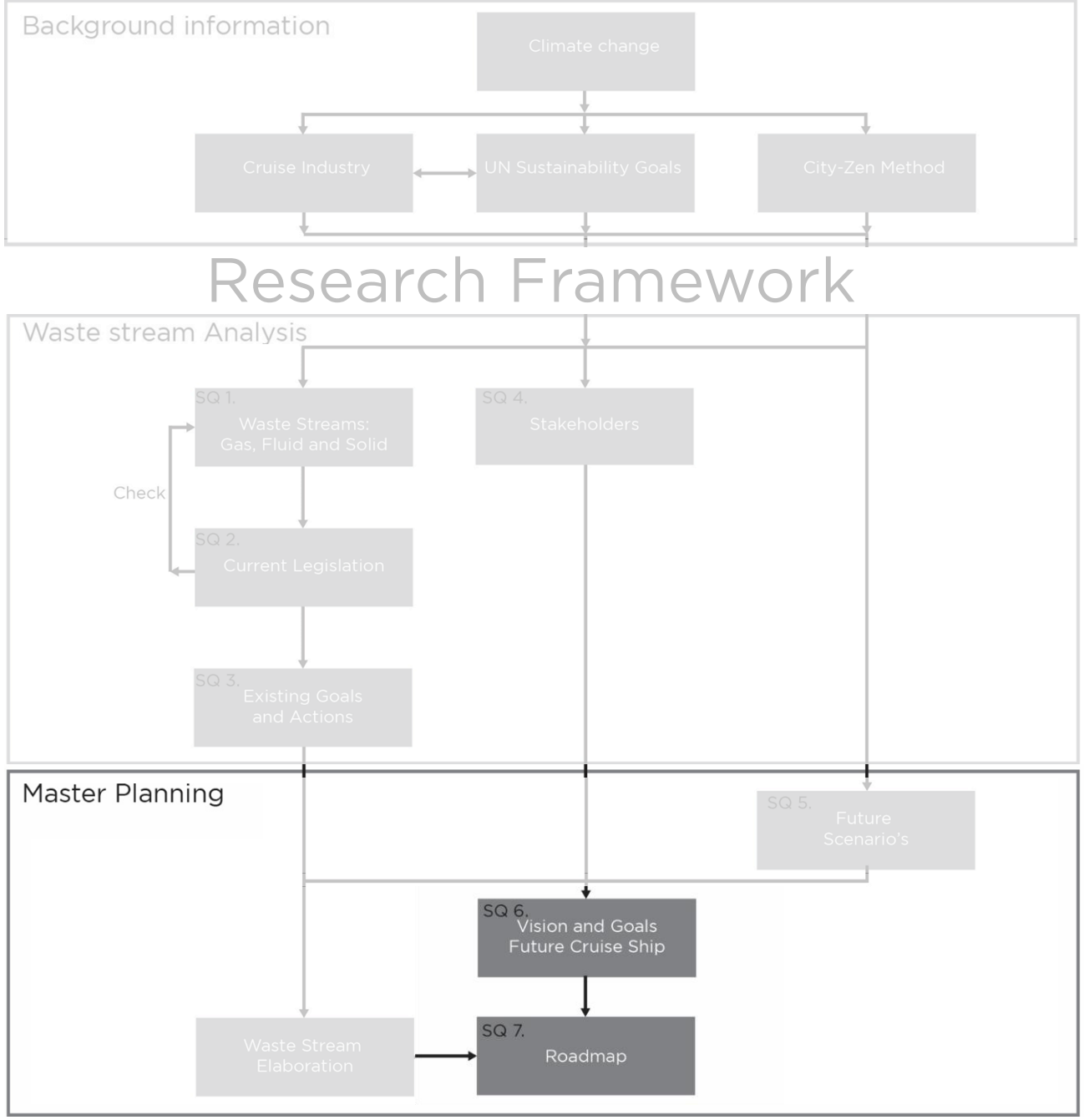


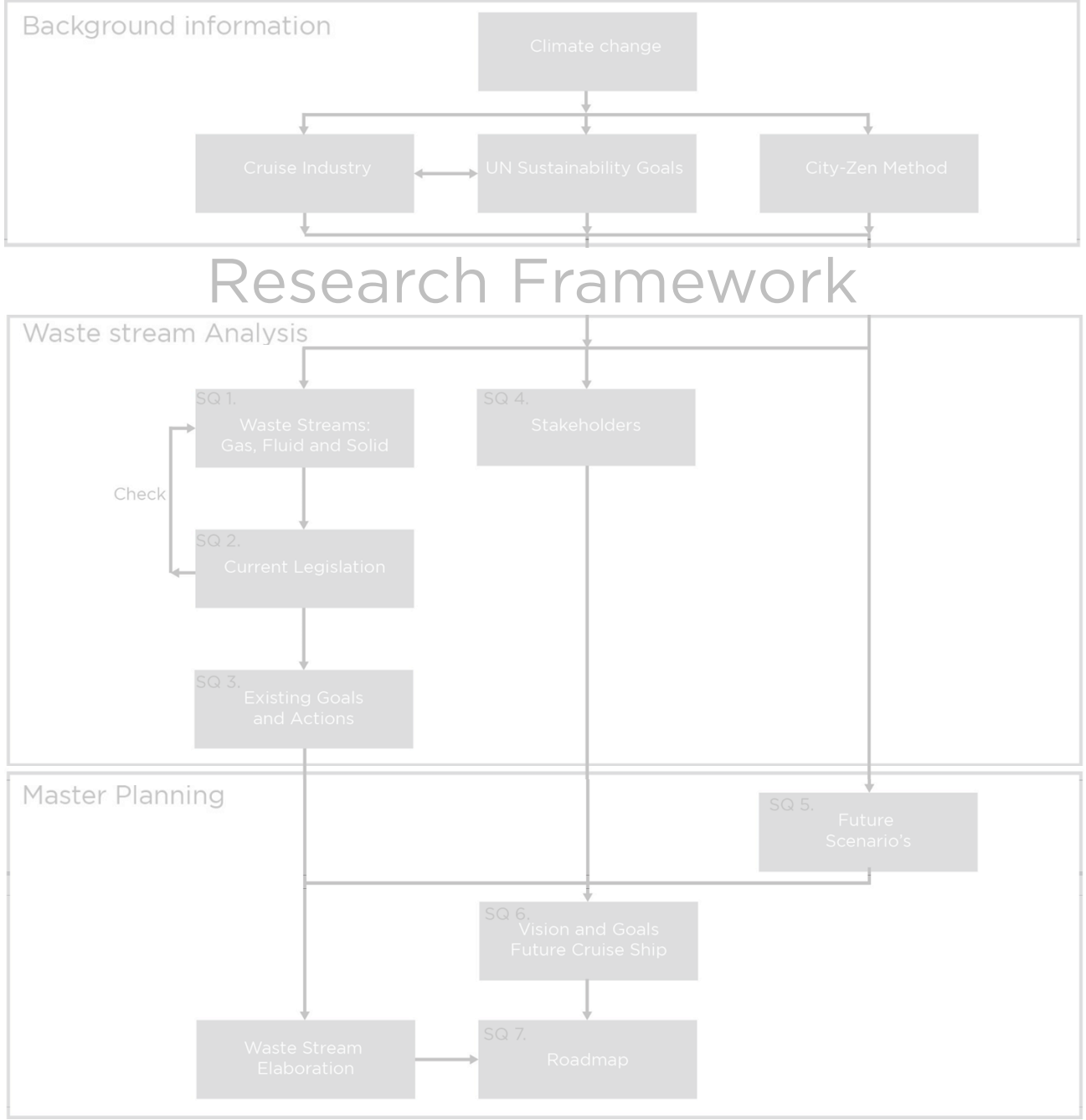
Research Framework



Research Framework




Background information
Climate change
Cruise Industry
UN Sustainability Goals
City-Zen Method
Research Framework
Waste stream Analysis
SQ 1.
Waste Streams:
Gas, Fluid and Solid
SQ 4.
Stakeholders
Check
SQ 2.
Current Legislation
SQ 3.
Existing Goals
and Actions
Master Planning
SQ 5.
Future
Scenario's
SQ 6.
Vision and Goals
Future Cruise Ship
Waste Stream
Elaboration
SQ 7.
Roadmap



Possible Future Cruise Ship

Garlick, M. (n.d.)

United Nations, (n.d.)

Marriedwithwanderlust, (2018)

30 Million

Royal Caribbean, (n.d.)

5500 + 2000

Hof Staff, (2017)

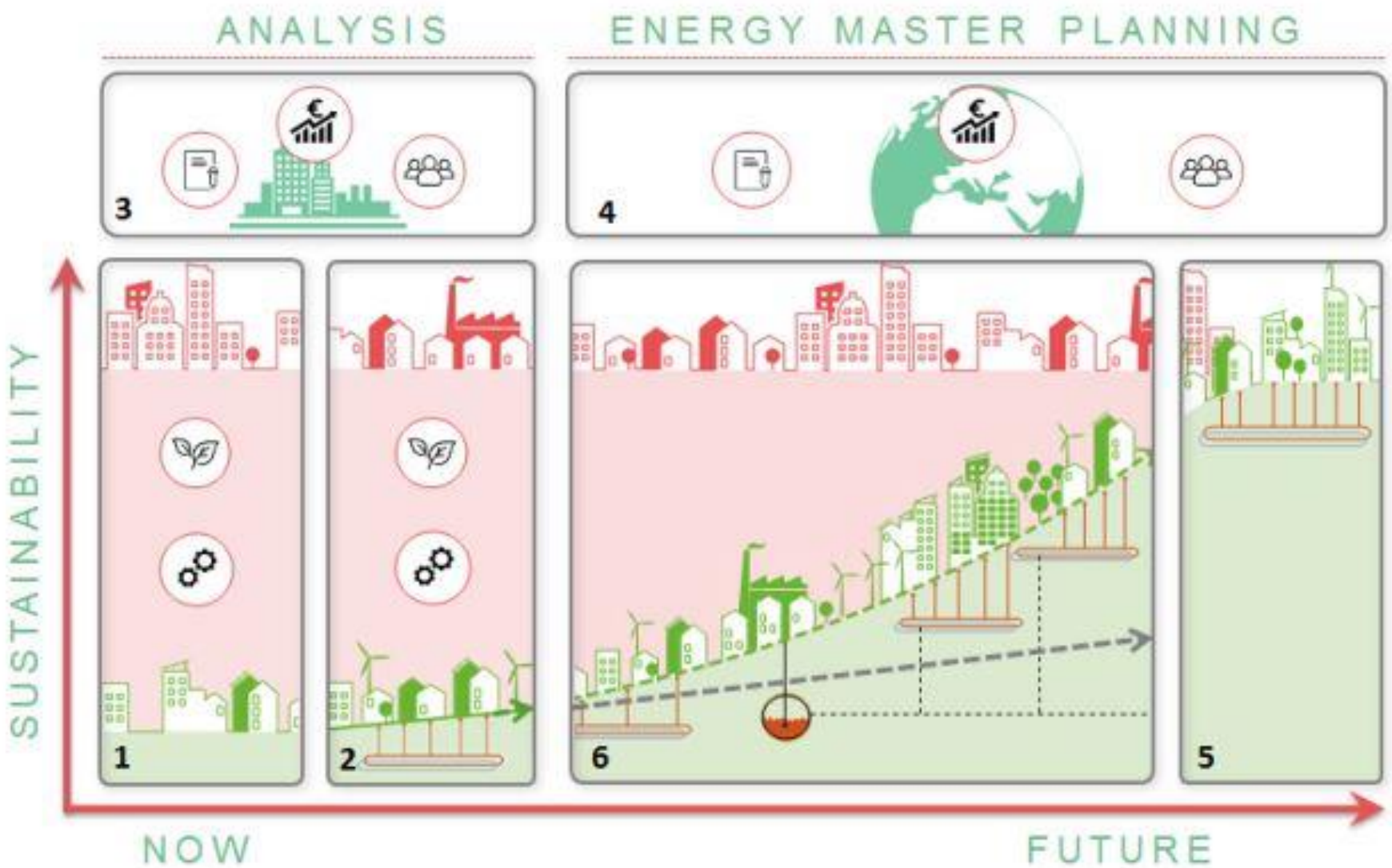
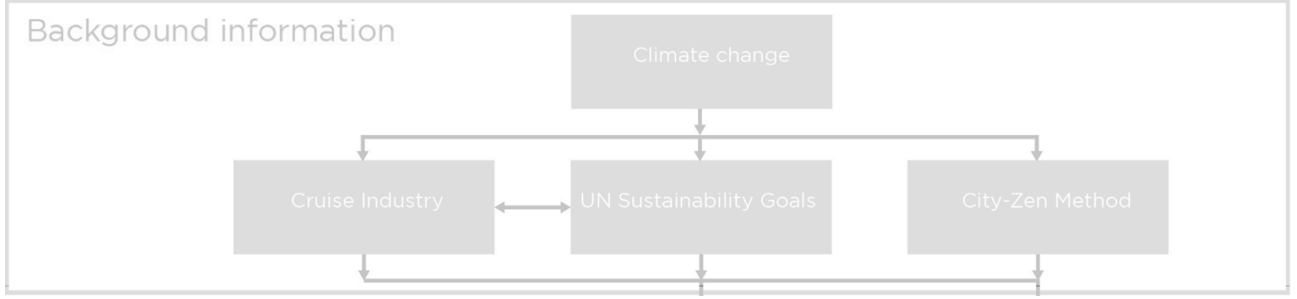


Figure 1: City-zen energy transition methodology.
ANALYSIS: Step 1: Basic energy analysis, Step 2: Present planning and trends, Step 3: Stakeholder analysis.
ENERGY MASTER PLANNING: Step 4: Scenario for the future, Step 5: Energy vision, Step 6: Roadmap.

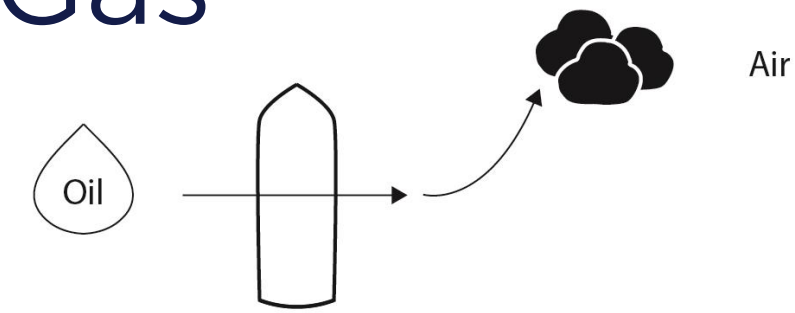
Van den Dobbelsteen et al, (2019)



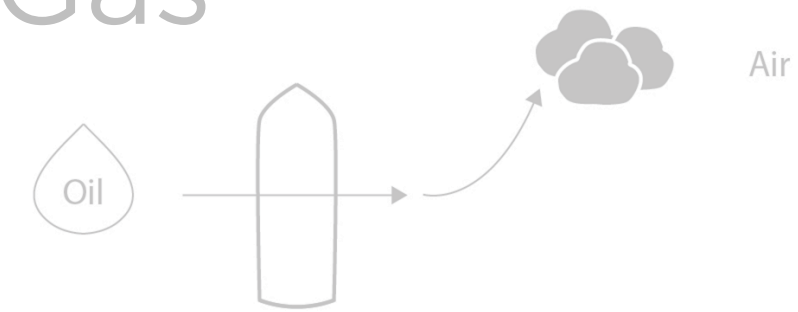
Research Framework

“ Waste streams from cruise ships come back into nature which negatively influences the environment.”

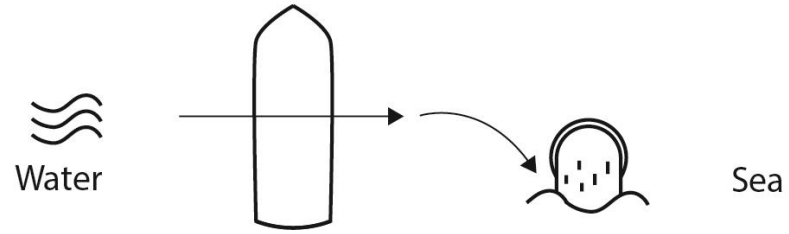
Gas



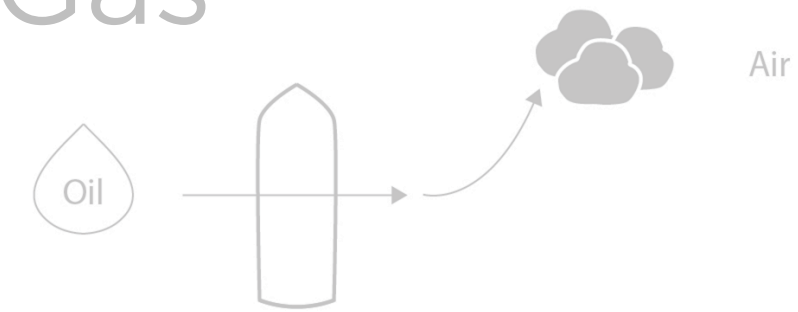
Gas



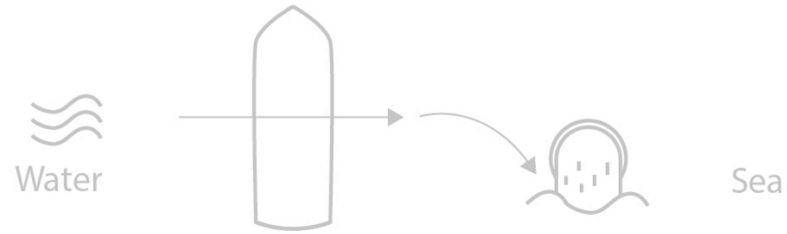
Fluid



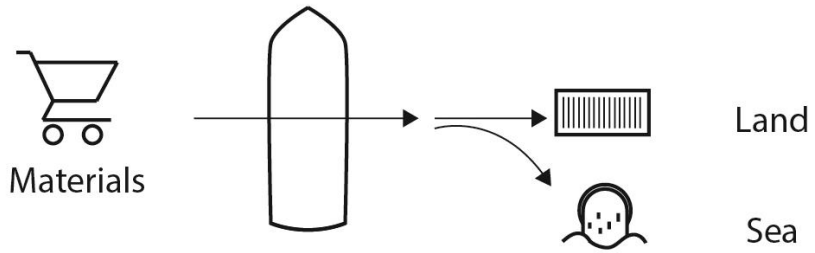
Gas



Fluid

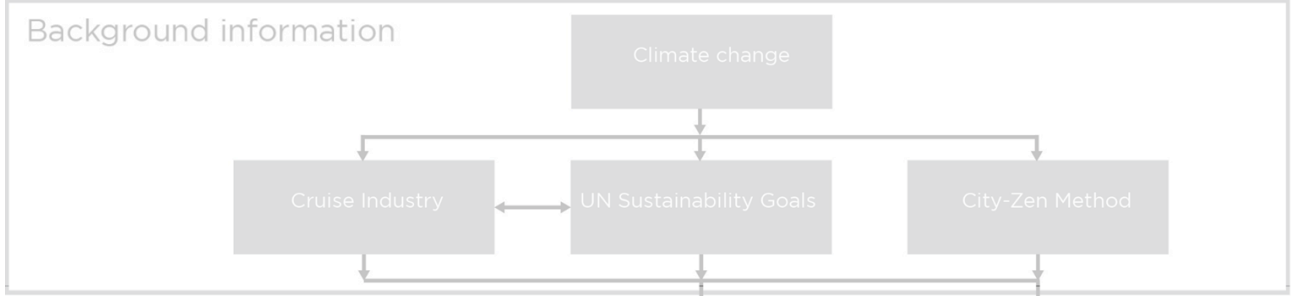


Solid

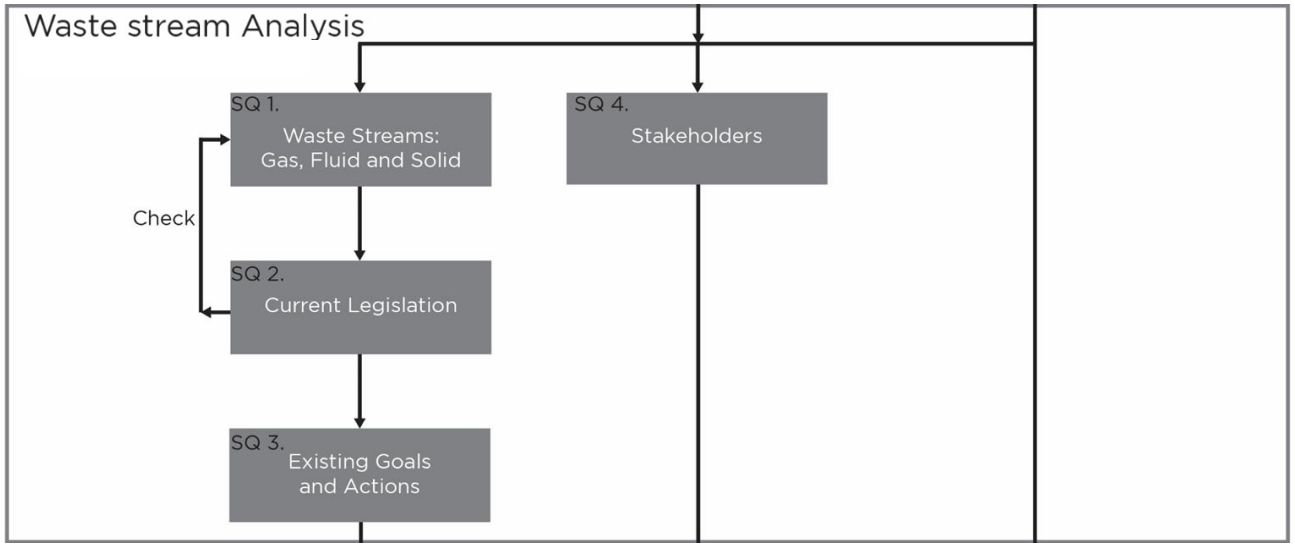


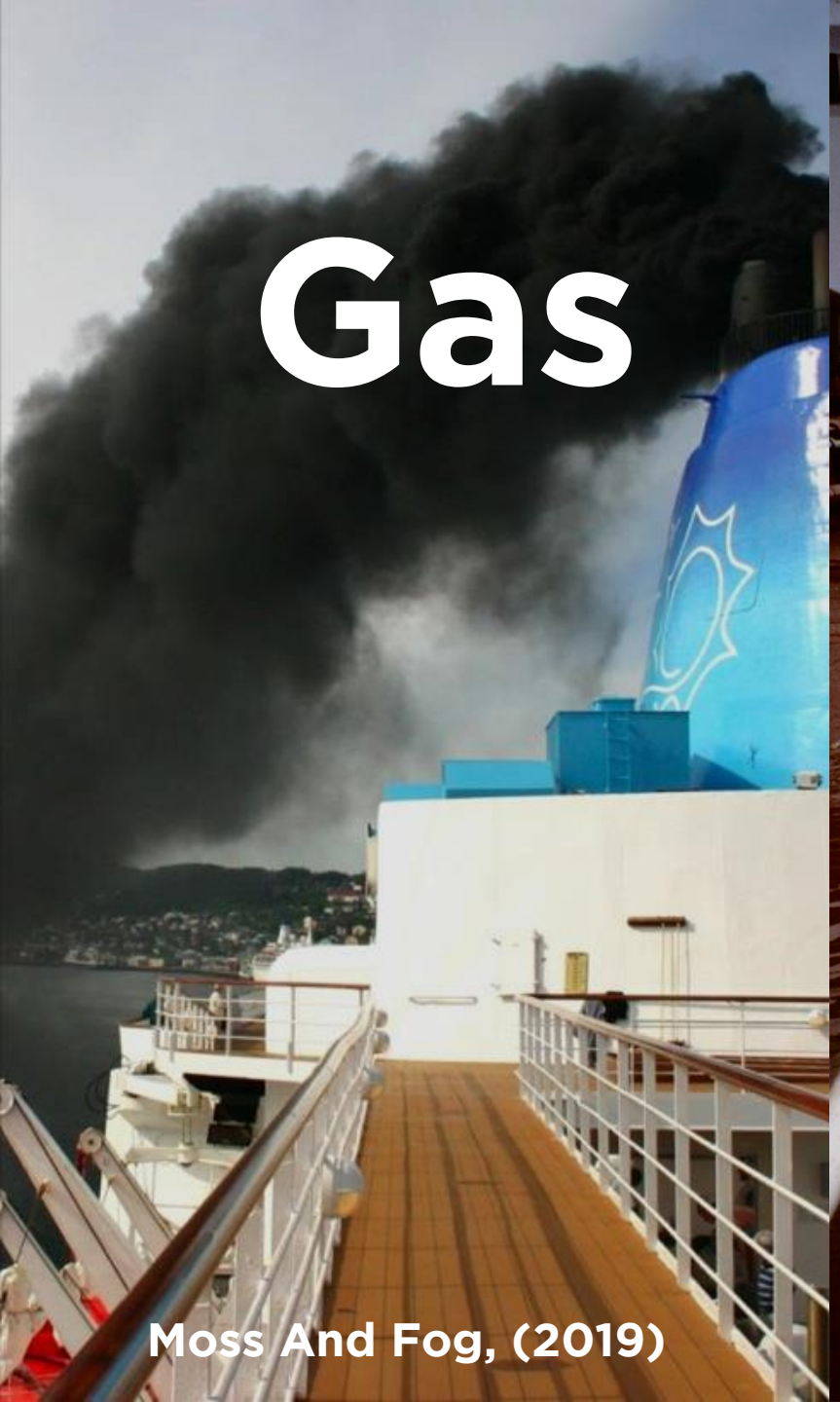
‘’To **contribute** to the **development of sustainable, circular cruise ships**. Specifically, the gas-, fluid- and solid waste streams.‘’

The **final product** is a **roadmap,** based on waste stream analyses, towards a set of targets and goals.



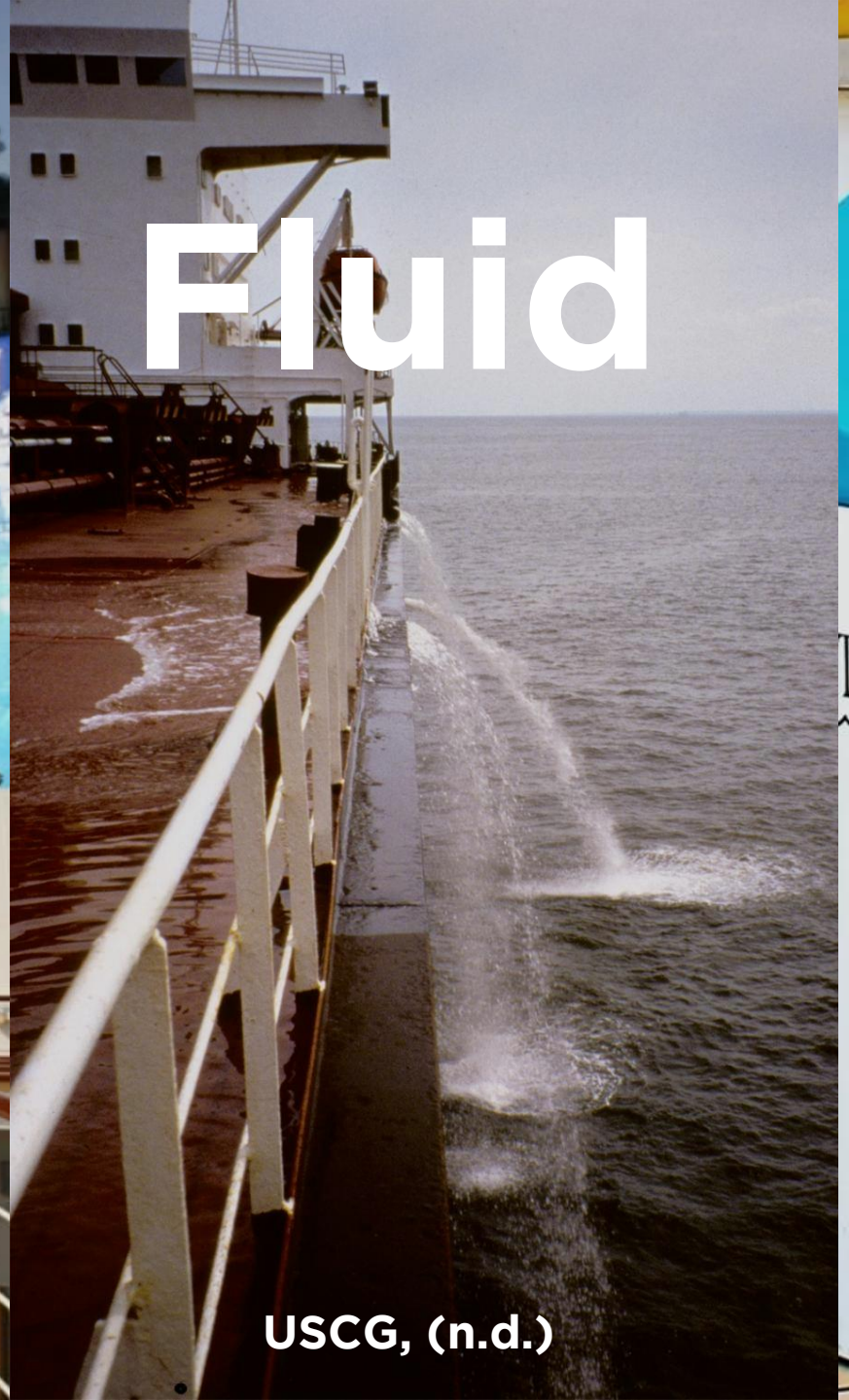
Research Framework





Gas

Moss And Fog, (2019)

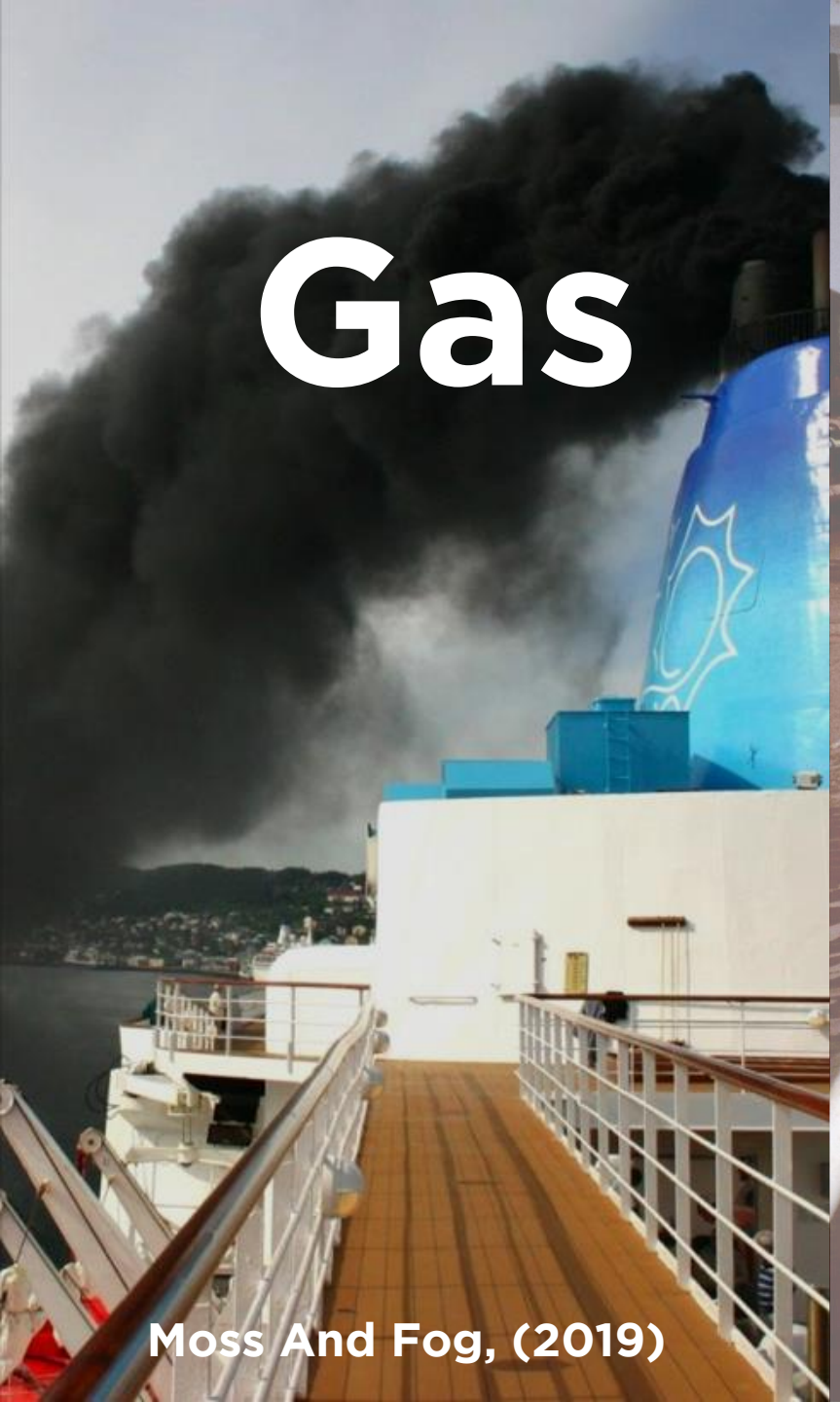


Fluid

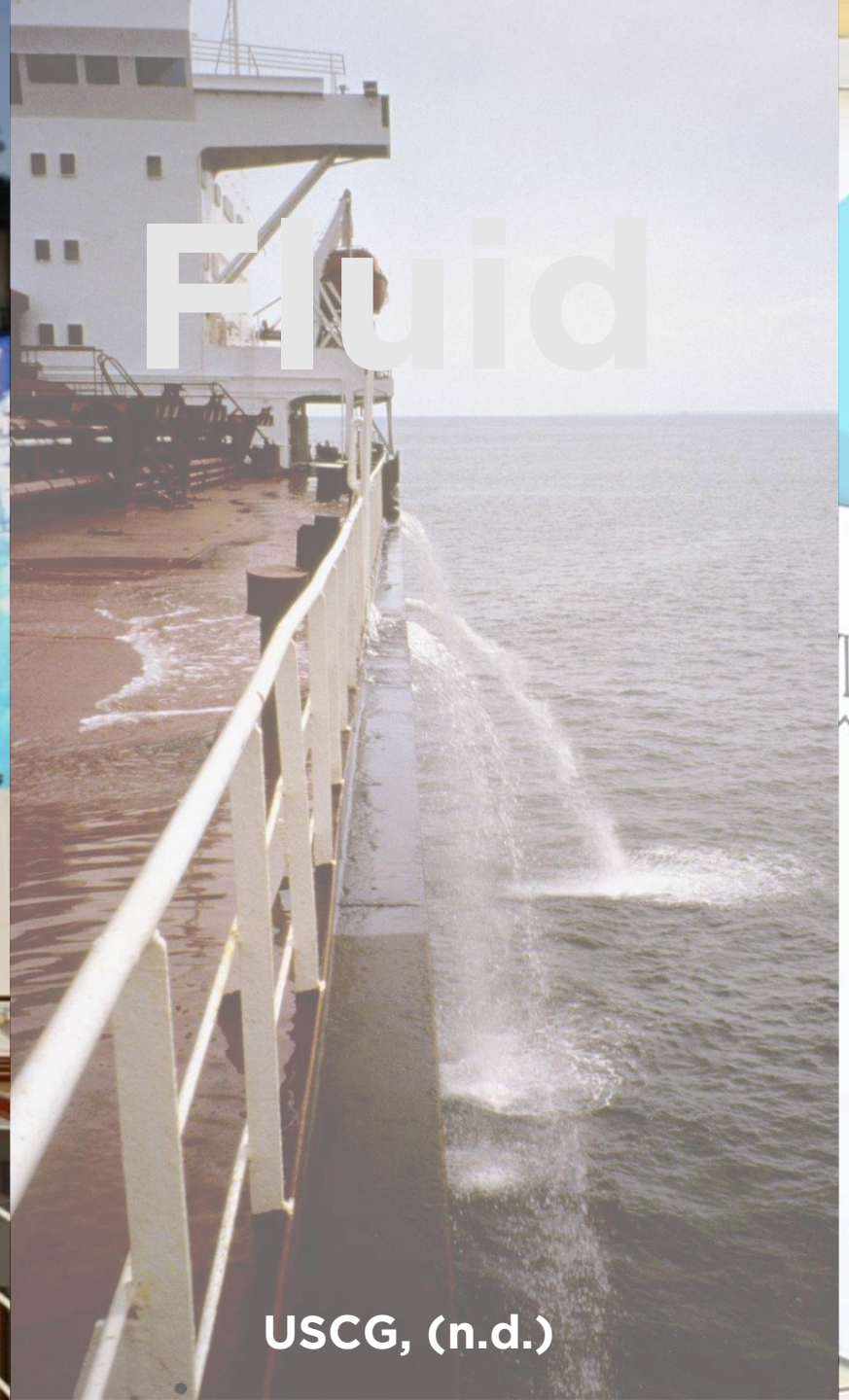
USCG, (n.d.)

Solid

Less Haines, (n.d.)



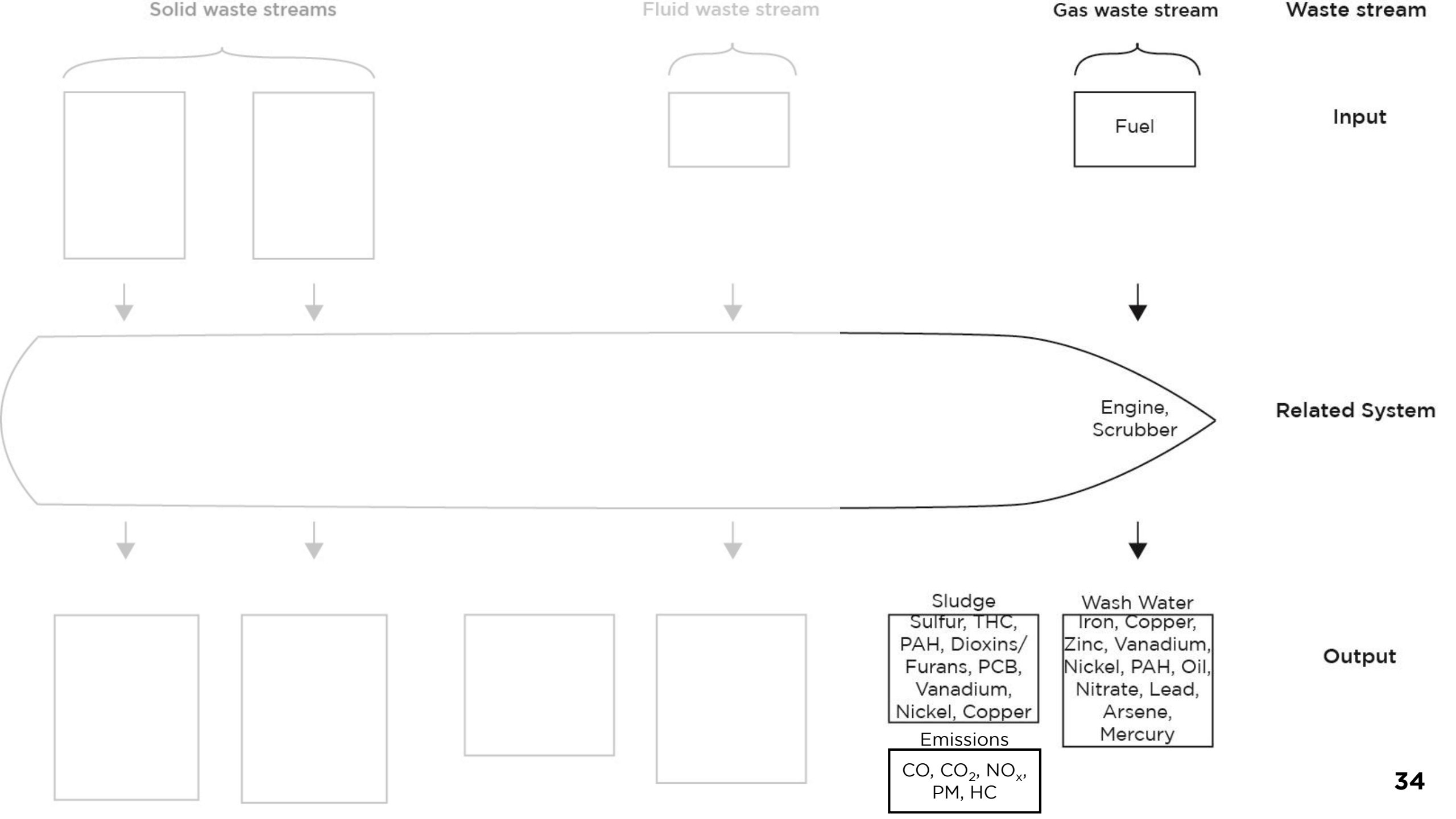
Moss And Fog, (2019)

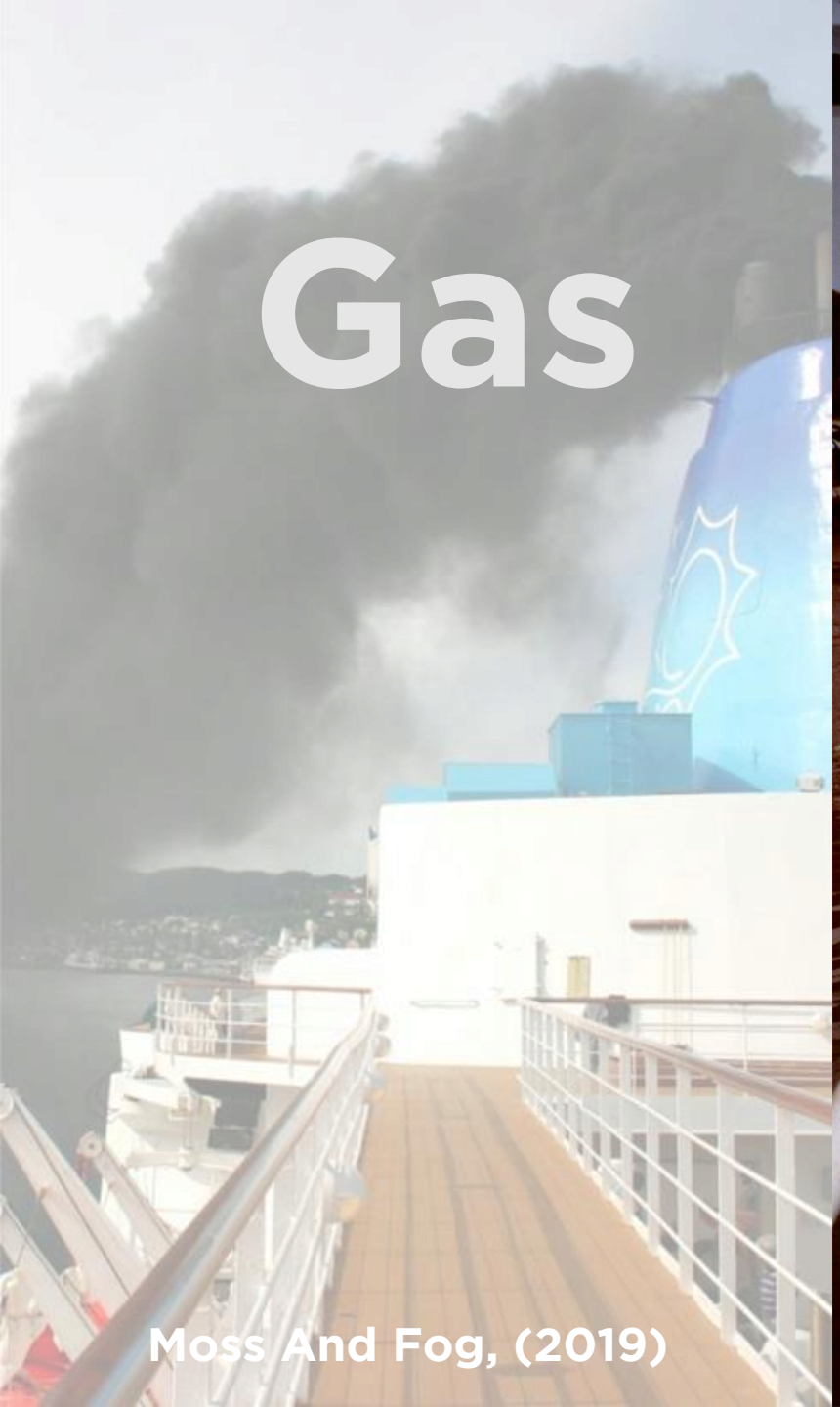


USCG, (n.d.)

Less Haines, (n.d.)

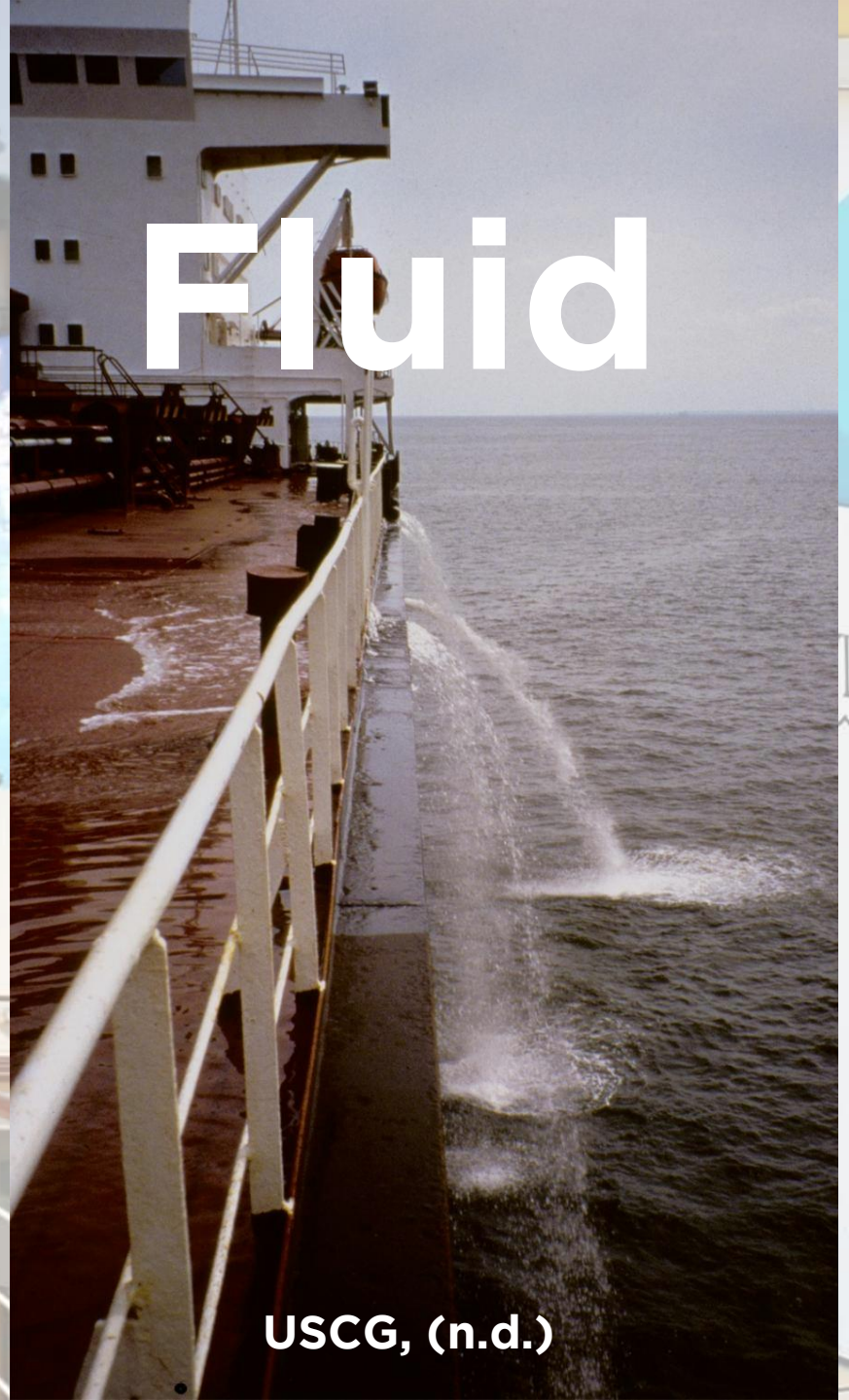
Van Gameren, D. (2020)


Solid waste streams
Fluid waste stream
Gas waste stream
Waste stream
Fuel
Input
Engine,
Scrubber
Related System
Sludge
Sulfur, THC, PAH, Dioxins/ Furans, PCB, Vanadium, Nickel, Copper
Wash Water
Iron, Copper, Zinc, Vanadium, Nickel, PAH, Oil, Nitrate, Lead, Arsene, Mercury
Emissions
CO, CO_2, NO_x, PM, HC
Output



Gas

Moss And Fog, (2019)



Fluid

USCG, (n.d.)

Solid

Less Haines, (n.d.)

1.Black Water

Jotun, (n.d.)

1.Black Water 2.Grey Water

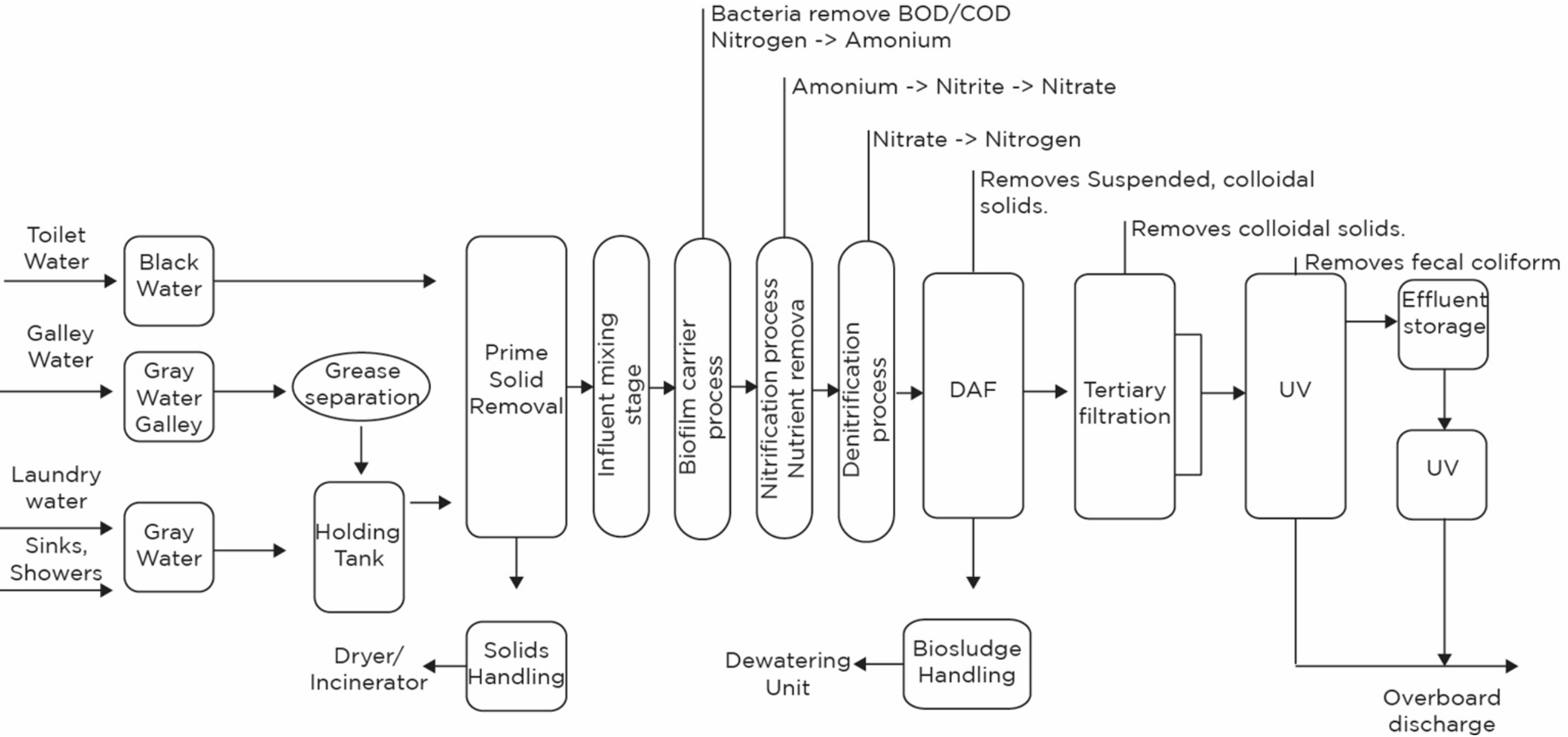
Jotun, (n.d.)

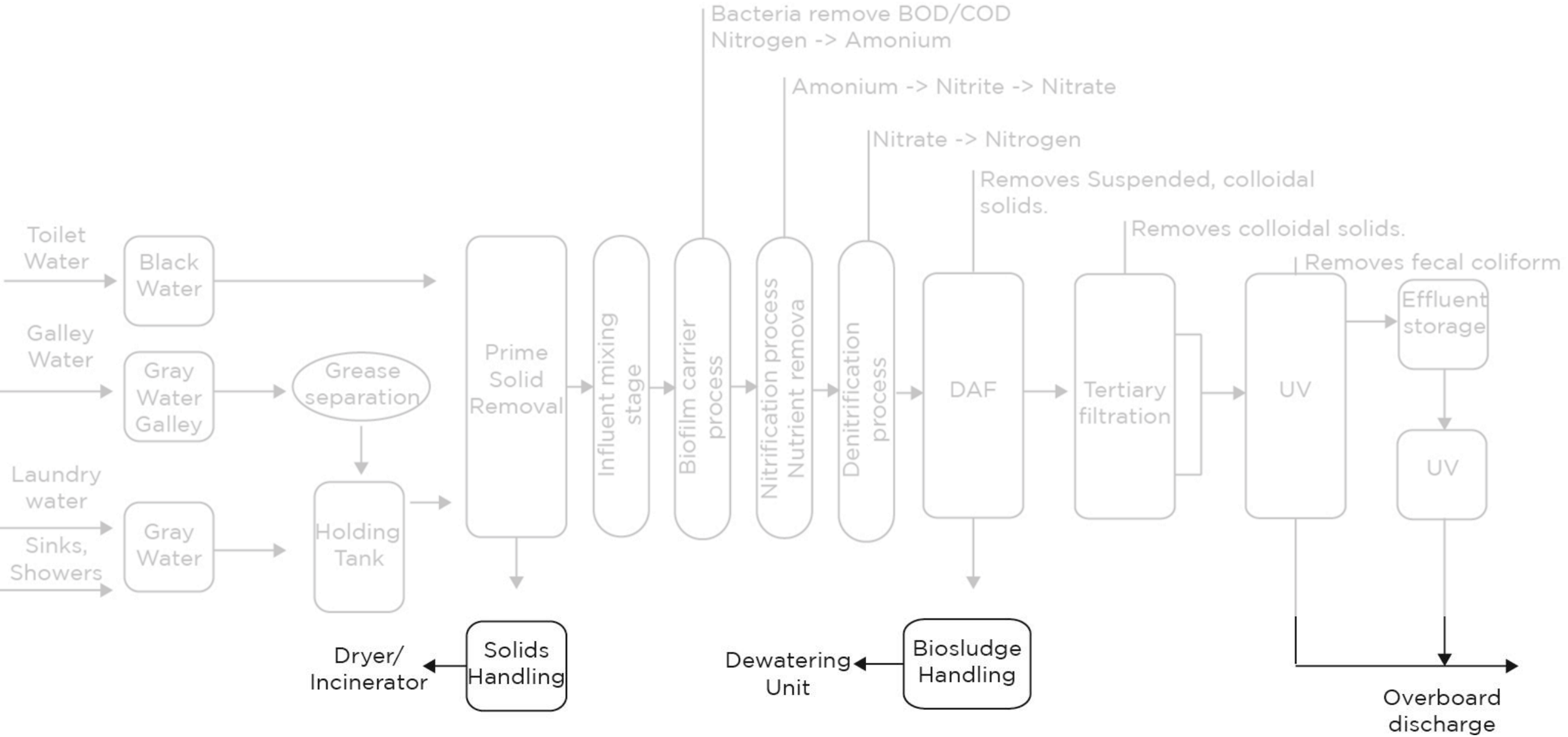
Jotun, (n.d.)

1.Black Water 2.Grey Water 3.Ballast Water

4.Bilge Water

Jotun, (n.d.)


Bacteria remove BOD/COD
Nitrogen -> Amonium
Amonium -> Nitrite -> Nitrate
Nitrate -> Nitrogen
Removes Suspended, colloidal solids.
Removes colloidal solids.
Removes fecal coliform
Toilet Water
Black Water
Galley Water
Gray Water Galley
Grease separation
Laundry water
Sinks, Showers
Gray Water
Holding Tank
Prime Solid Removal
Influent mixing stage
Biofilm carrier process
Nitrification process Nutrient remova
Denitrification process
DAF
Tertiary filtration
UV
Effluent storage
UV
Dryer/ Incinerator
Solids Handling
Dewatering Unit
Biosludge Handling
Overboard discharge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Toilet Water
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Galley Water
Gray Water Galley
Grease separation
Laundry water
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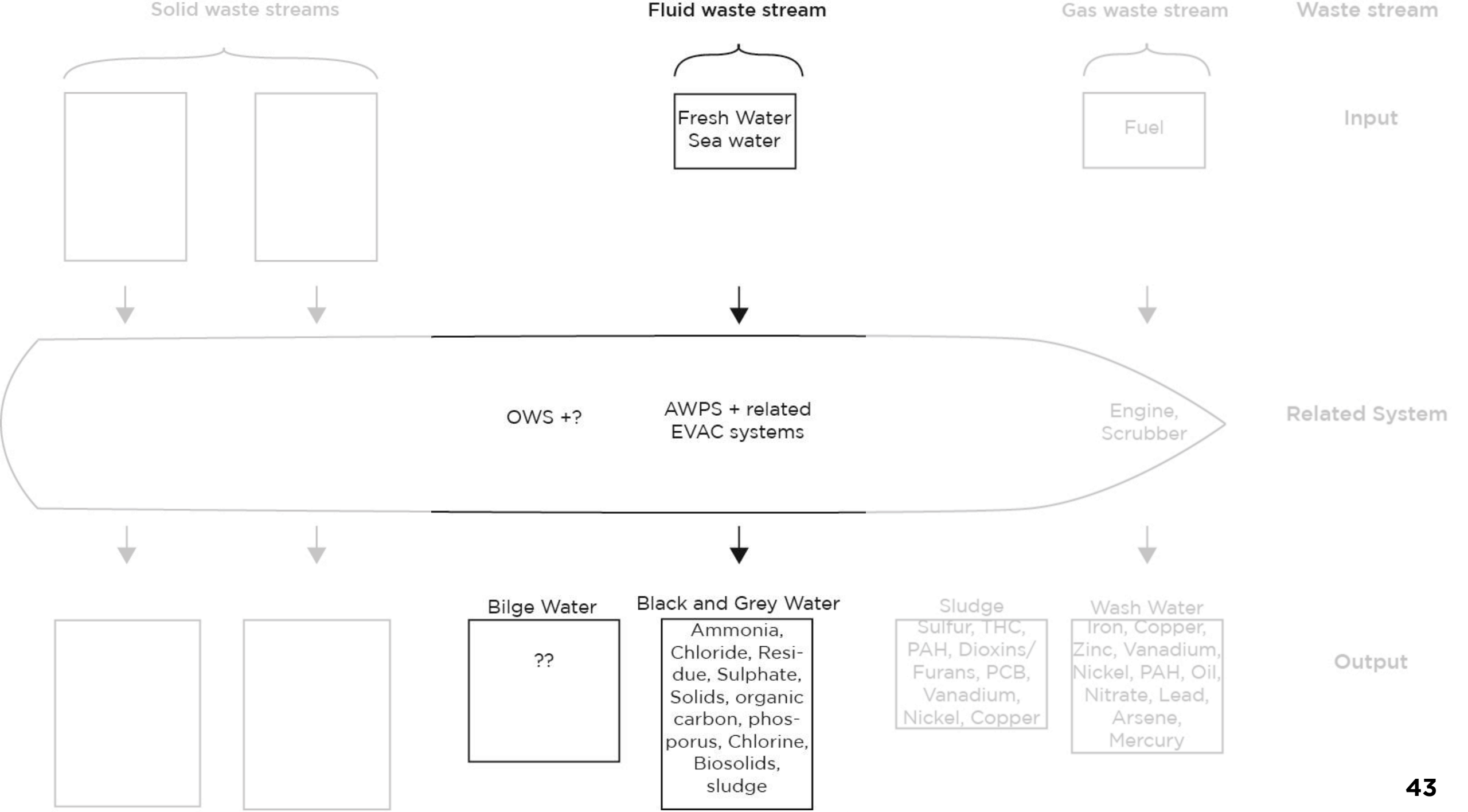
Holding Tank
Prime Solid Removal
Influent mixing stage
Biofilm carrier process
Nitrification process Nutrient remova
Denitrification process
DAF
Tertiary filtration
UV
Effluent storage
UV
Dryer/ Incinerator
Solids Handling
Dewatering Unit
Biosludge Handling
Overboard discharge

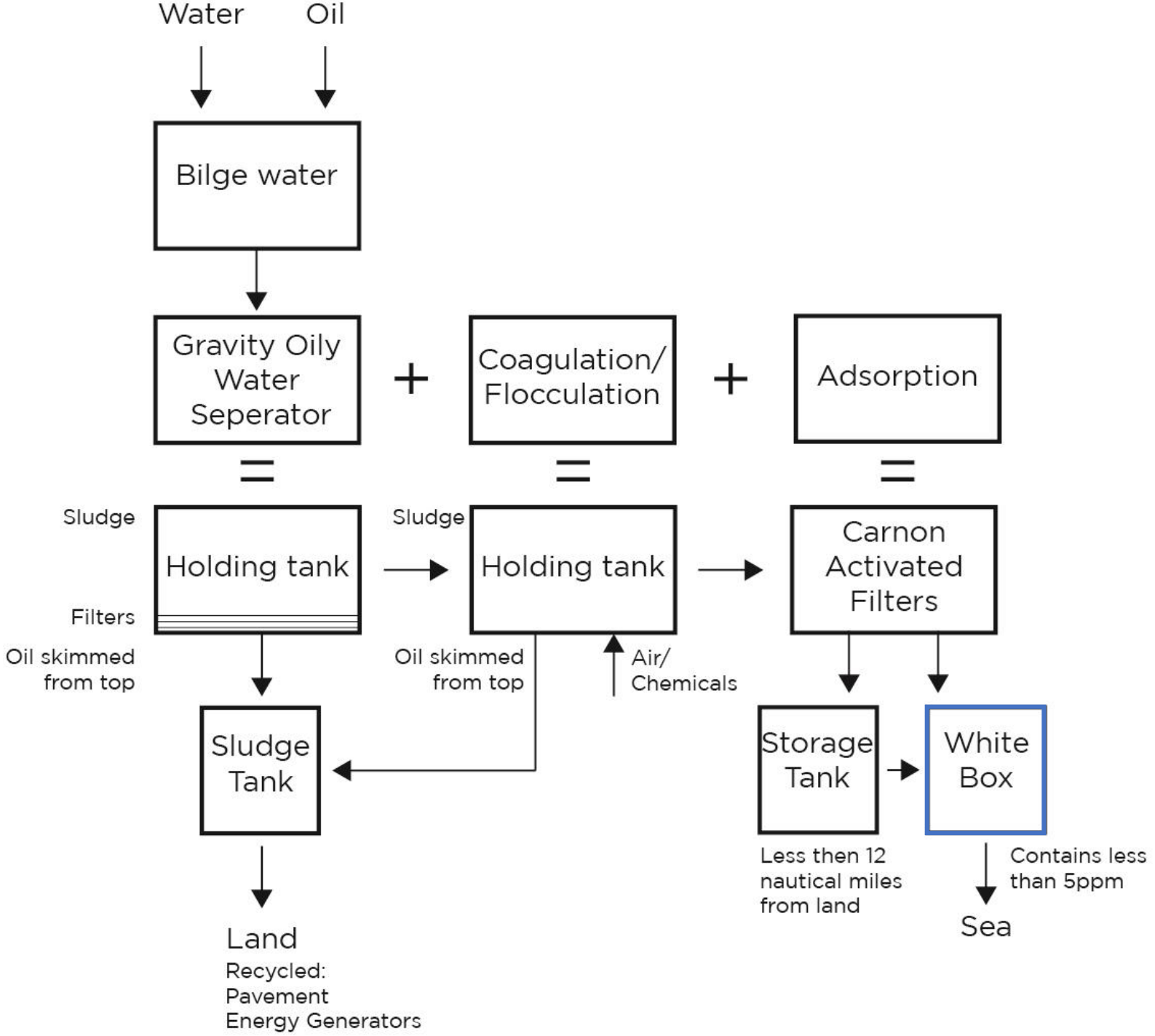
Component
(partly) Removed
Ammonia Nitrogen mg/L as N
BOD5 mg/L
COD mg/L
Faecal Coliform
Hexane Extractable Material (Oil and Grease) mg/L
Nitrate mg/L
Nitrite mg/L
Total Kjeldahl Nitrogen mg/L (Nitrogen contained in organic substances and inorganic compounds)
Properties that must be met
Alkalinity mg/L (capacity to resist pH changes)
Conductivity uS/cm (capability to pass electrical flow)
Temperature °C
pH
Turbidity mg/L
Not verified
Chloride mg/L
Settable Residue mg/L
Sulfate mg/L
Total Dissolved solids mg/L (Organic and inorganic substances)
Total organic carbon mg/L (Acids, fats, sugars, proteins, enzymes, and hydrocarbon fuels)
Total phosphorous mg/L
Total Residual Chlorine mg/L
TSS mg/L Total suspended solids


Solid waste streams
Fluid waste stream
Gas waste stream
Waste stream
Fresh Water
Sea water
Fuel
Input
OWS +?
AWPS + related
EVAC systems
Engine,
Scrubber
Related System
Bilge Water
??
Black and Grey Water
Ammonia, Chloride, Residue, Sulphate, Solids, organic carbon, phosporus, Chlorine, Biosolids, sludge
Sludge
Sulfur, THC, PAH, Dioxins/ Furans, PCB, Vanadium, Nickel, Copper
Wash Water
Iron, Copper, Zinc, Vanadium, Nickel, PAH, Oil, Nitrate, Lead, Arsene, Mercury
Output

OWS + a Polishing treatment process

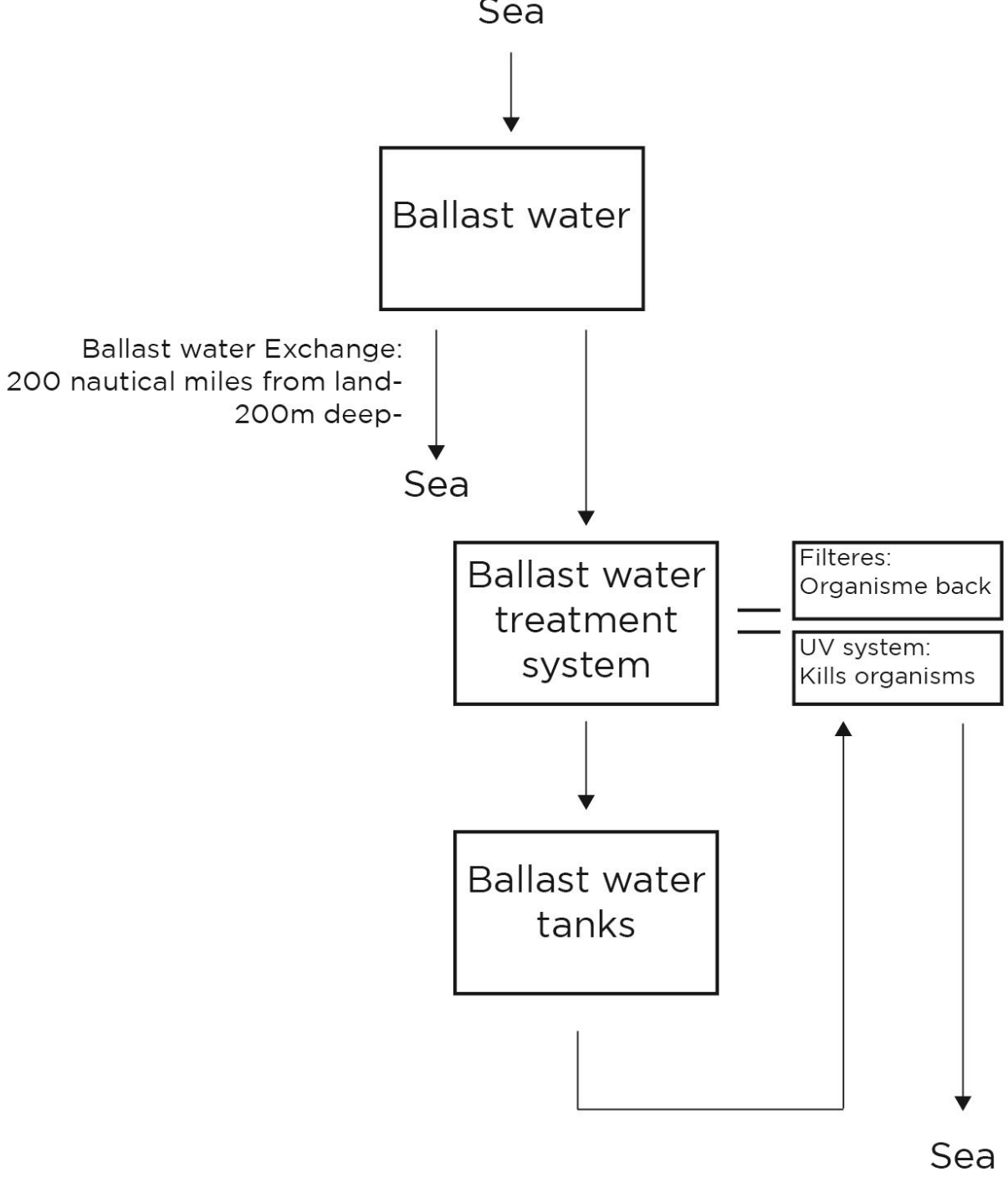
Polishing treatment processes:

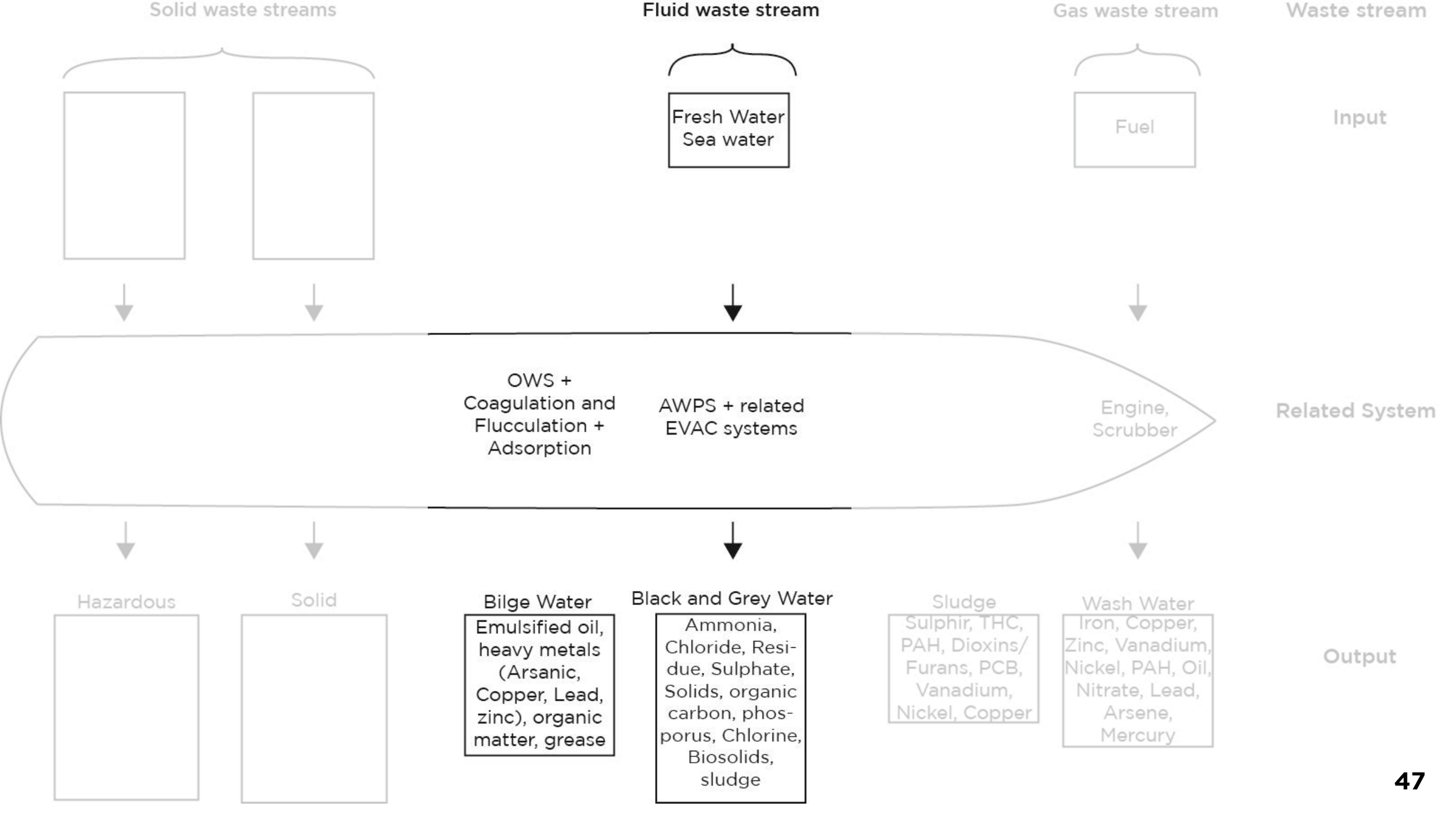
- **Absorption and Adsorption**
- Biological Treatment
- **Coagulation and Flocculation**
- Flotation
- Membrane Technologies (ultrafiltration).

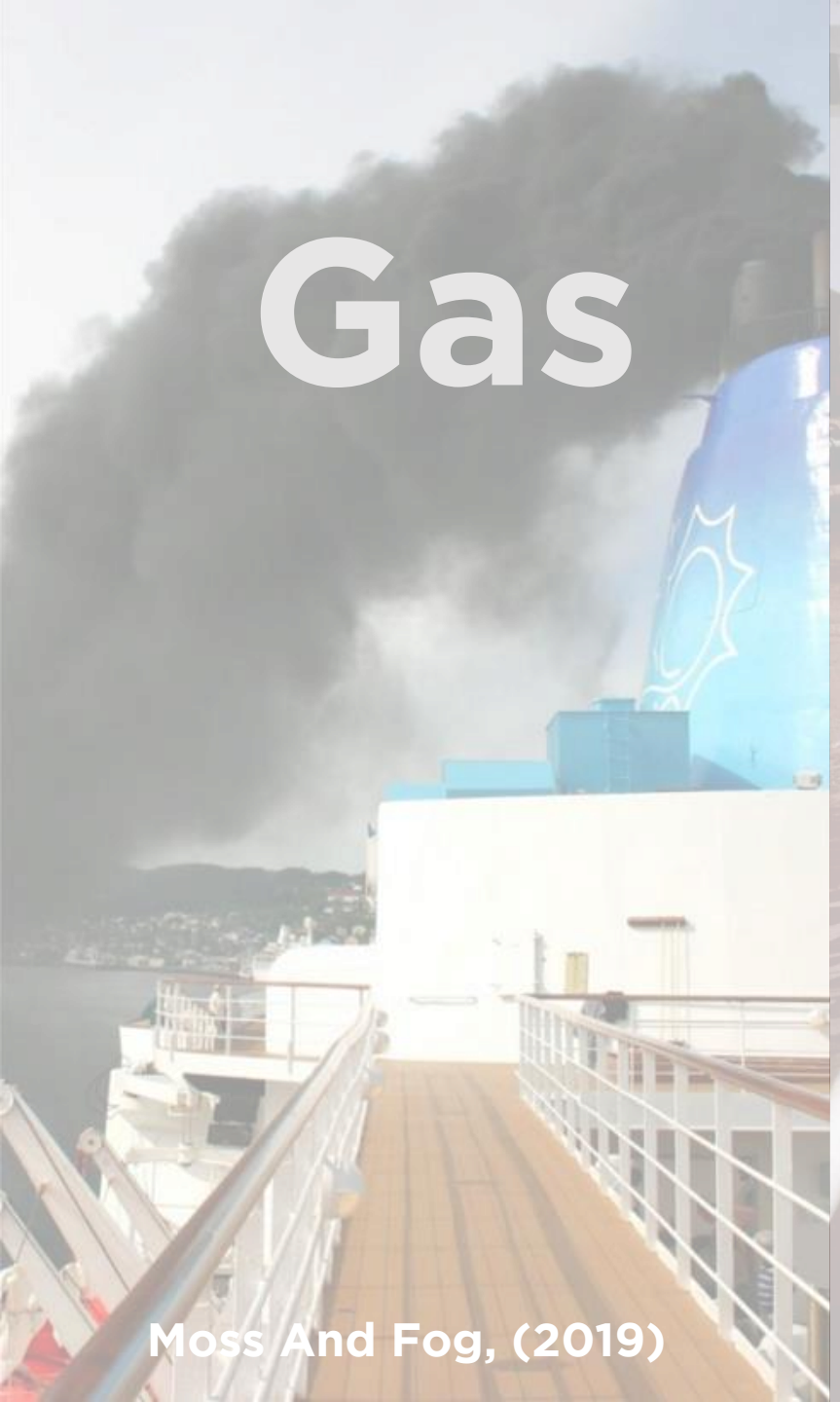


But still contains:

- Heavy metals
- Emulsified oils

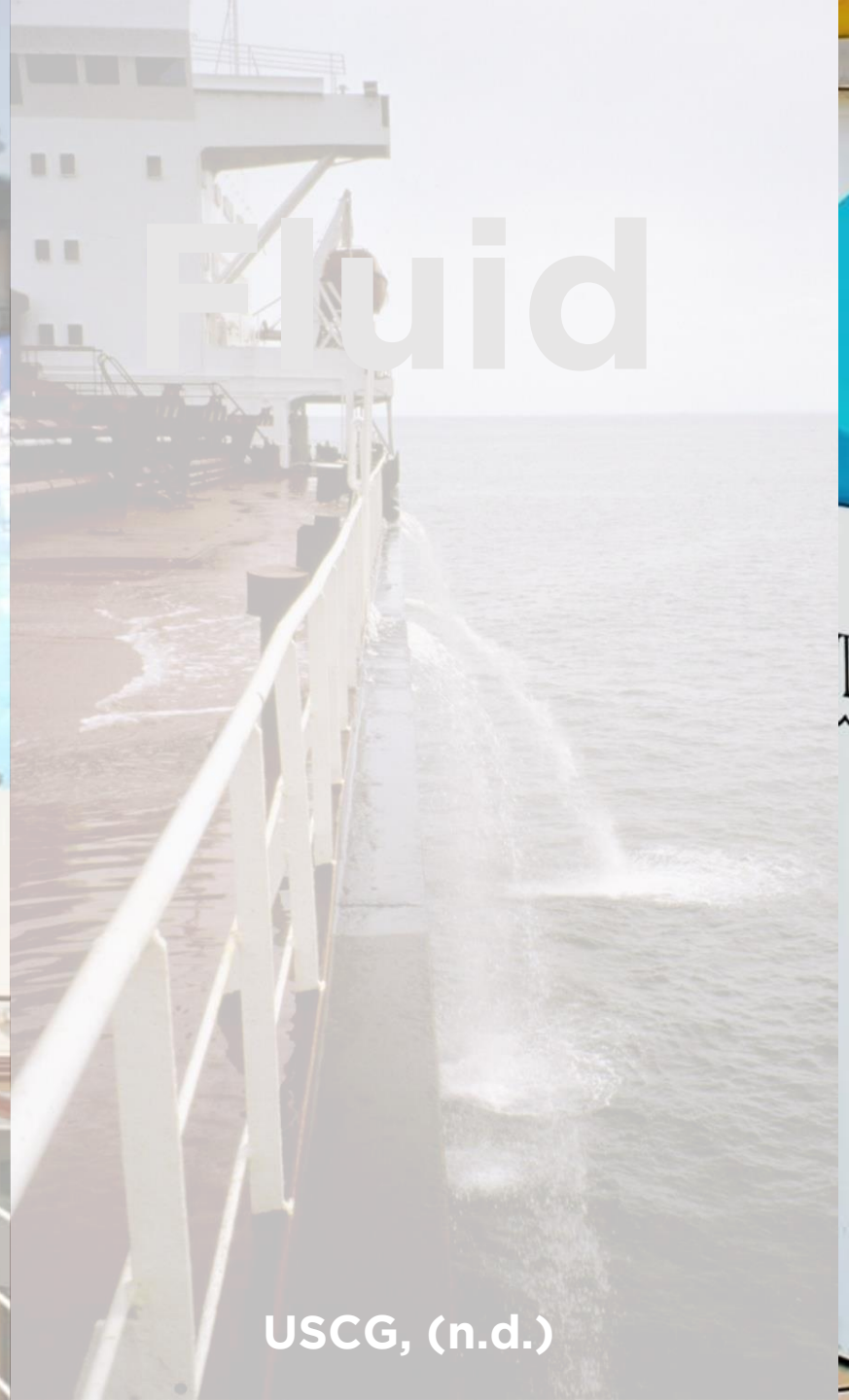

Sea
Ballast water
Ballast water Exchange:
200 nautical miles from land-
200m deep-
Sea
Ballast water treatment system
Filteres:
Organisme back
UV system:
Kills organisms
Ballast water tanks
Sea


Solid waste streams
Fluid waste stream
Gas waste stream
Waste stream
Fresh Water
Sea water
Fuel
Input
OWS +
Coagulation and
Flucculation +
Adsorption
AWPS + related
EVAC systems
Engine,
Scrubber
Related System
Hazardous
Solid
Bilge Water
Emulsified oil, heavy metals (Arsanic, Copper, Lead, zinc), organic matter, grease
Black and Grey Water
Ammonia, Chloride, Residue, Sulphate, Solids, organic carbon, phosporus, Chlorine, Biosolids, sludge
Sludge
Sulphir, THC, PAH, Dioxins/ Furans, PCB, Vanadium, Nickel, Copper
Wash Water
Iron, Copper, Zinc, Vanadium, Nickel, PAH, Oil, Nitrate, Lead, Arsene, Mercury
Output



Gas

Moss And Fog, (2019)



Fluid

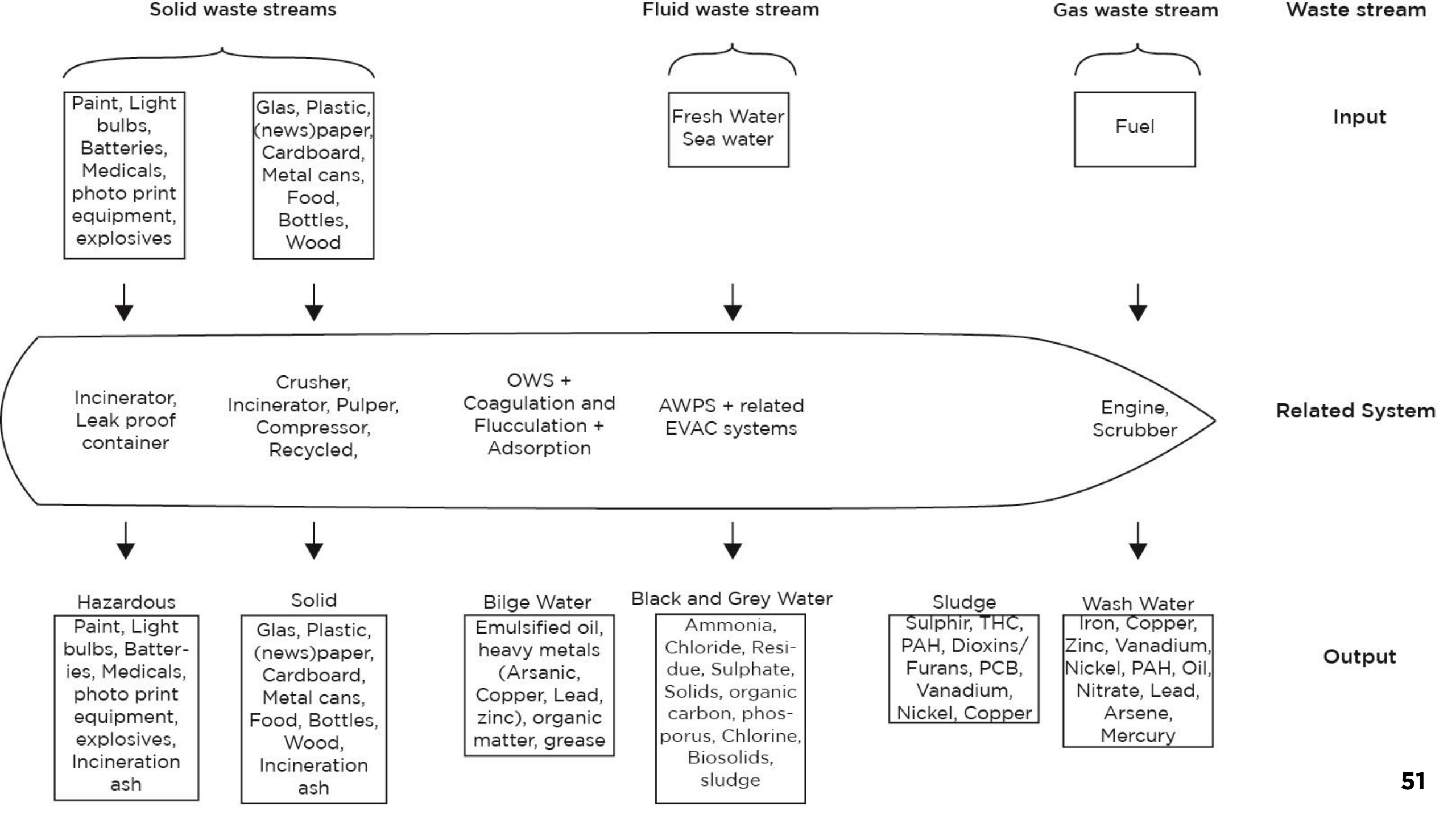
USCG, (n.d.)

Solid

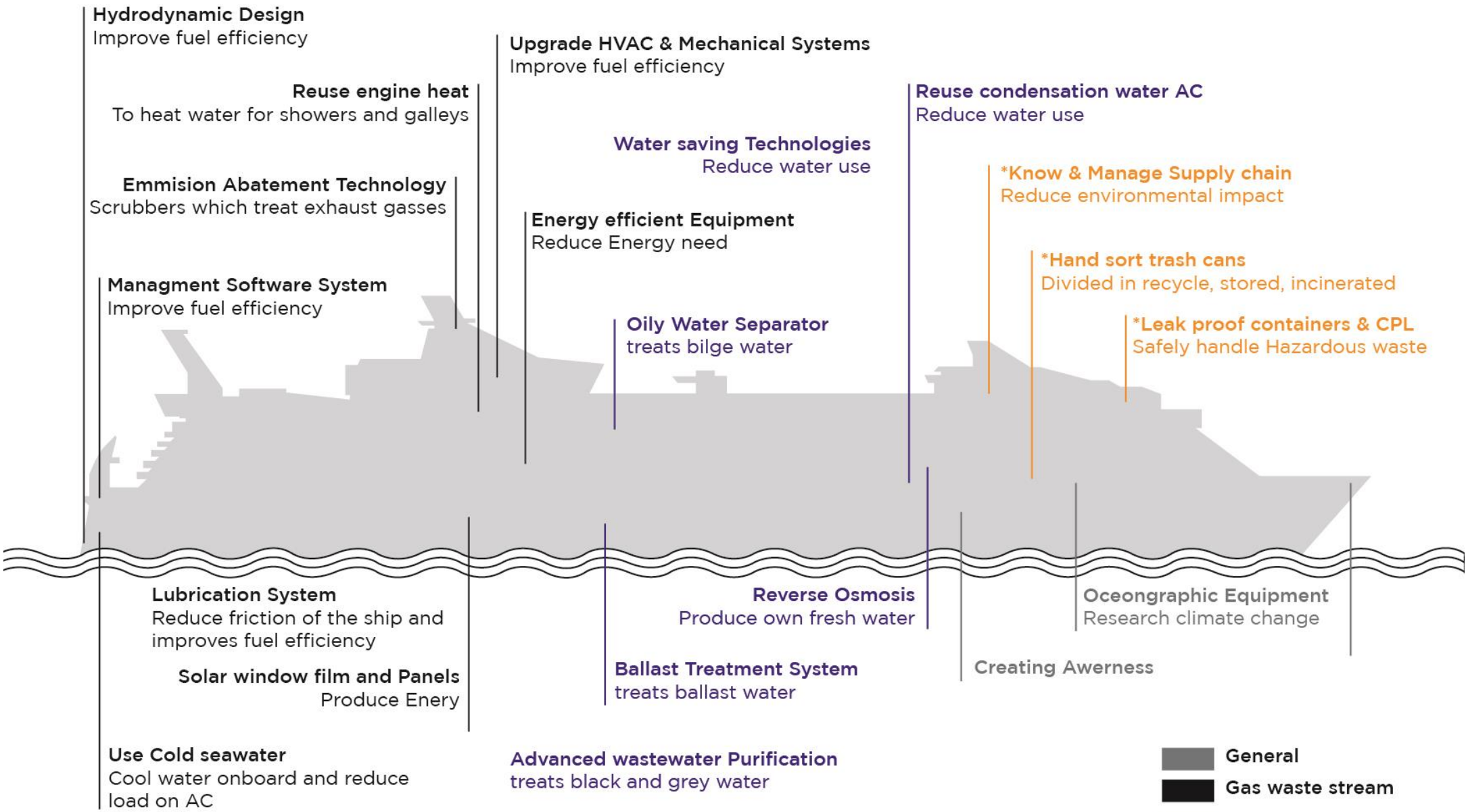
Less Haines, (n.d.)

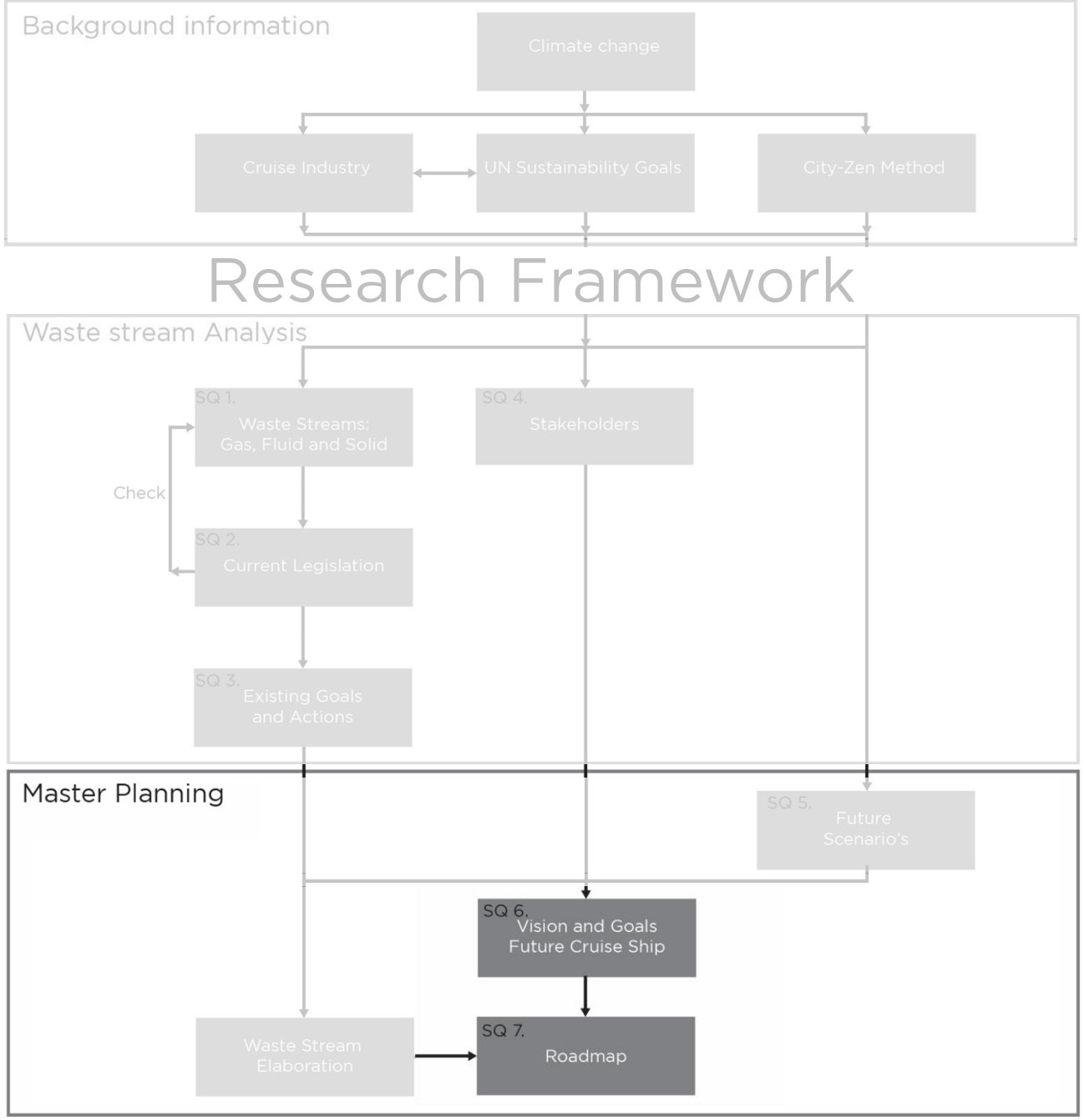
Non-hazardous Solid Waste	Used for	Treatment	Ends up
Glass	Food and beverage jars & bottles.	Crushed	Land
Plastic	ropes, containers, bags, biodegradable plastics, poly-ethylene terephthalate plastics, high-density polyethylene plastics	Incinerated, recycled	Land, Air, (Sea)
Aluminium & Metal Cans	Soft drink cans, tin cans (food), steel cans ship maintenance	Crushed, recycled	Land
Paper	Paper and packing	Incinerated, recycled	Land, Air, (Sea)
Cardboard	Dunnage, packing	Incinerated, recycled	Land, Air, (Sea)
Food waste	Food scraps, table refuse, galley refuse, food wrappers contaminated with food.	Pulped, compressed, incinerated	Land, Air, (Sea)
Wood	Pallets, waste wood	Incinerated	Land, Air, (Sea)
Incinerator ash	Ash from packing material, paper, cardboard, etc.	-	Sea

Hazardous waste	Hazardous waste Substances
Paints waste	Perchlorethylene
Incinerator ash	Hydrocarbons
Fluorescent and mercury vapour light bulbs	Chlorinated hydrocarbons
Batteries	Heavy metals
Medical waste	Solvents
Photo waste	Silver
Explosives	Aerosol liquids
Chemical	


Solid waste streams
Fluid waste stream
Gas waste stream
Waste stream
Paint, Light bulbs, Batteries, Medicals, photo print equipment, explosives
Glas, Plastic, (news)paper, Cardboard, Metal cans, Food, Bottles, Wood
Fresh Water Sea water
Fuel
Input
Incinerator, Leak proof container
Crusher, Incinerator, Pulper, Compressor, Recycled,
OWS + Coagulation and Flucculation + Adsorption
AWPS + related EVAC systems
Engine, Scrubber
Related System
Hazardous
Paint, Light bulbs, Batter-ies, Medicals, photo print equipment, explosives, Incineration ash
Solid
Glas, Plastic, (news)paper, Cardboard, Metal cans, Food, Bottles, Wood, Incineration ash
Bilge Water
Emulsified oil, heavy metals (Arsanic, Copper, Lead, zinc), organic matter, grease
Black and Grey Water
Ammonia, Chloride, Resi-due, Sulphate, Solids, organic carbon, phos-porus, Chlorine, Biosolids, sludge
Sludge
Sulphir, THC, PAH, Dioxins/ Furans, PCB, Vanadium, Nickel, Copper
Wash Water
Iron, Copper, Zinc, Vanadium, Nickel, PAH, Oil, Nitrate, Lead, Arsene, Mercury
Output

Taken measures by Royal Caribbean

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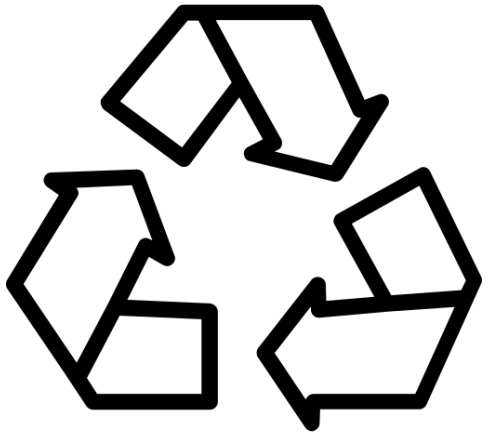
Vision and Goals
Future Cruise Ship
Waste Stream
Elaboration
SQ 7.
Roadmap

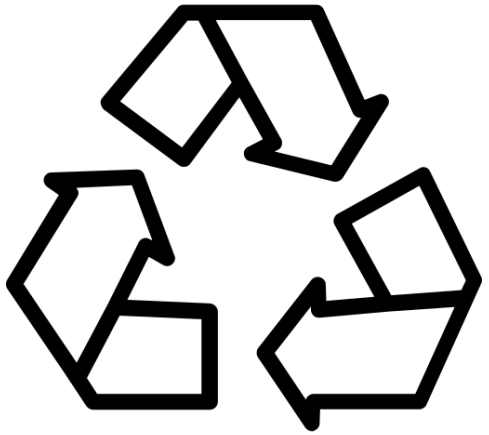
- A. Fully Circular



- B. Collaboration Cruise Ship & Harbour

- C. Positive effect on the Environment

- A. Fully Circular



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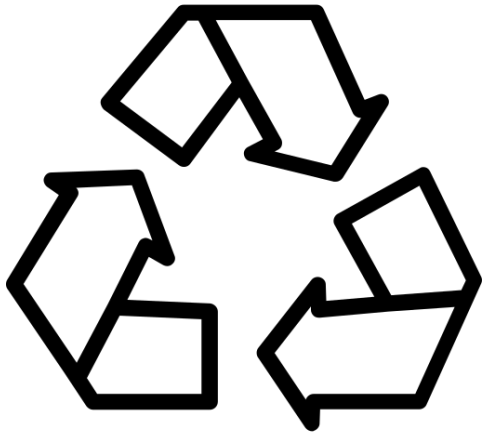

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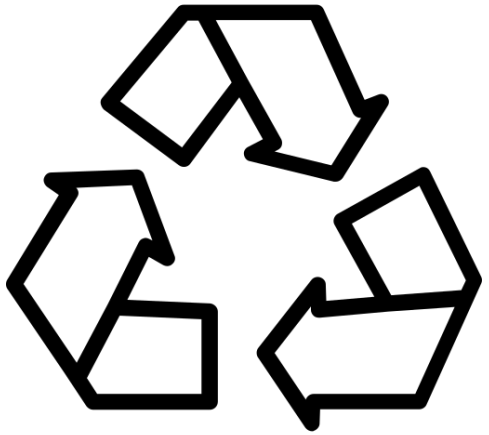

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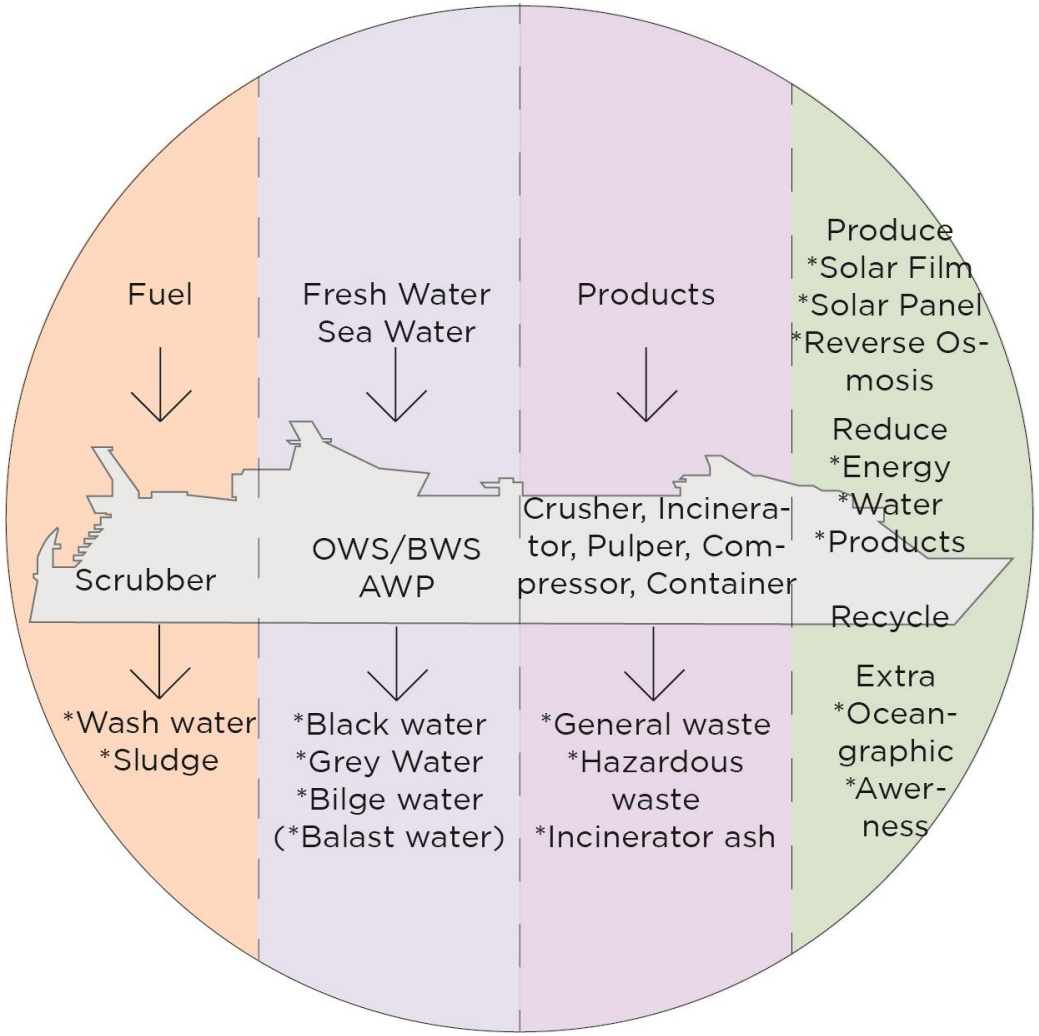
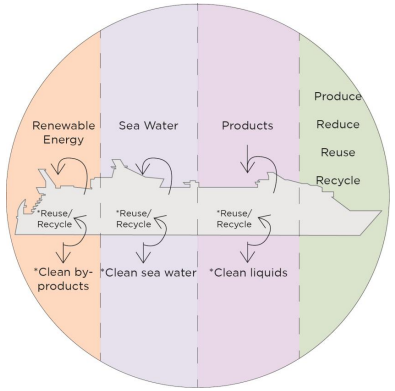
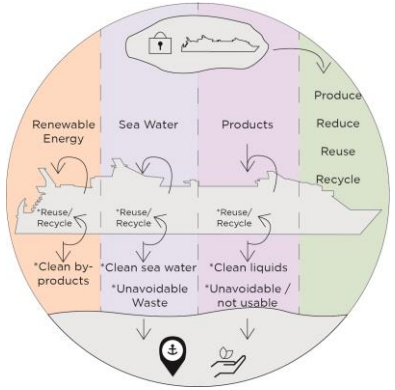


Today

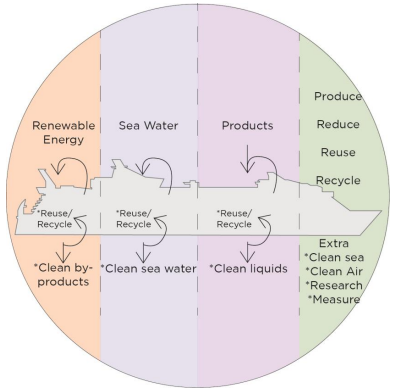
Roadmap A

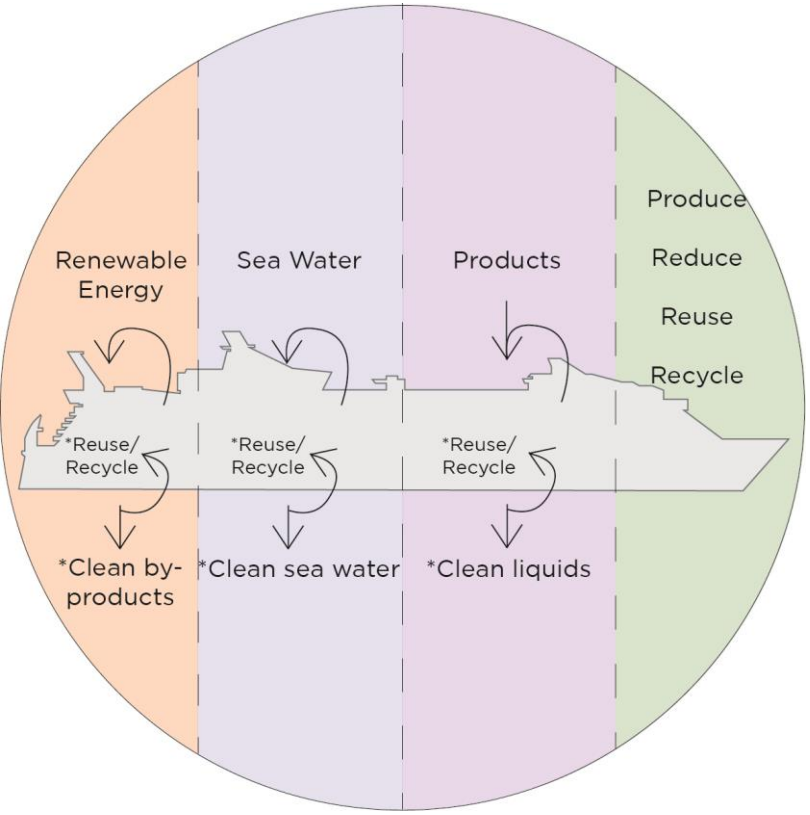


Roadmap B

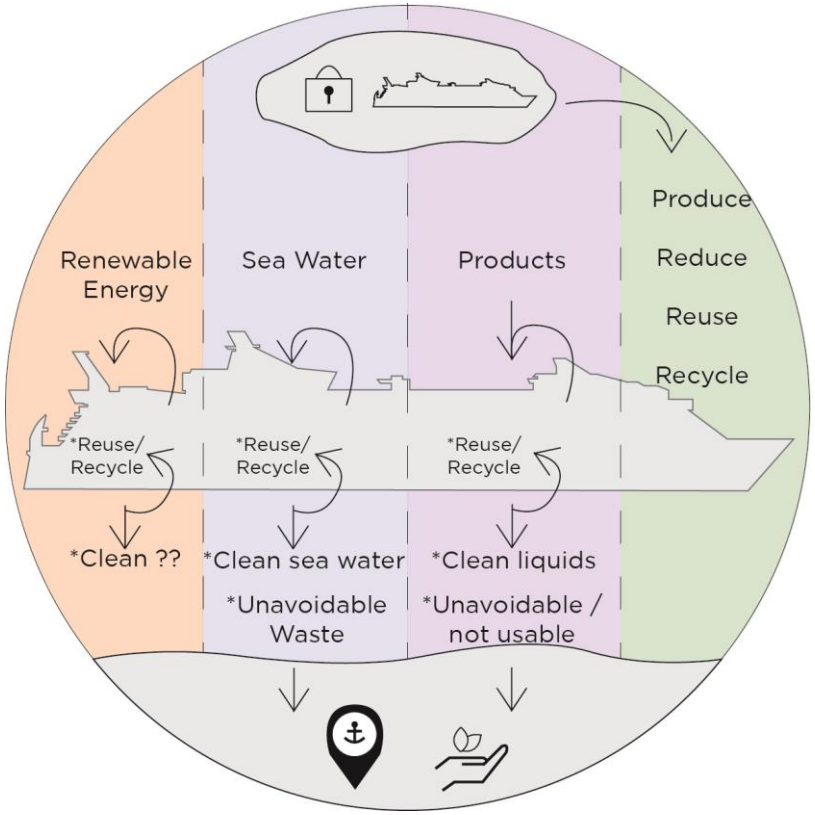


Roadmap C

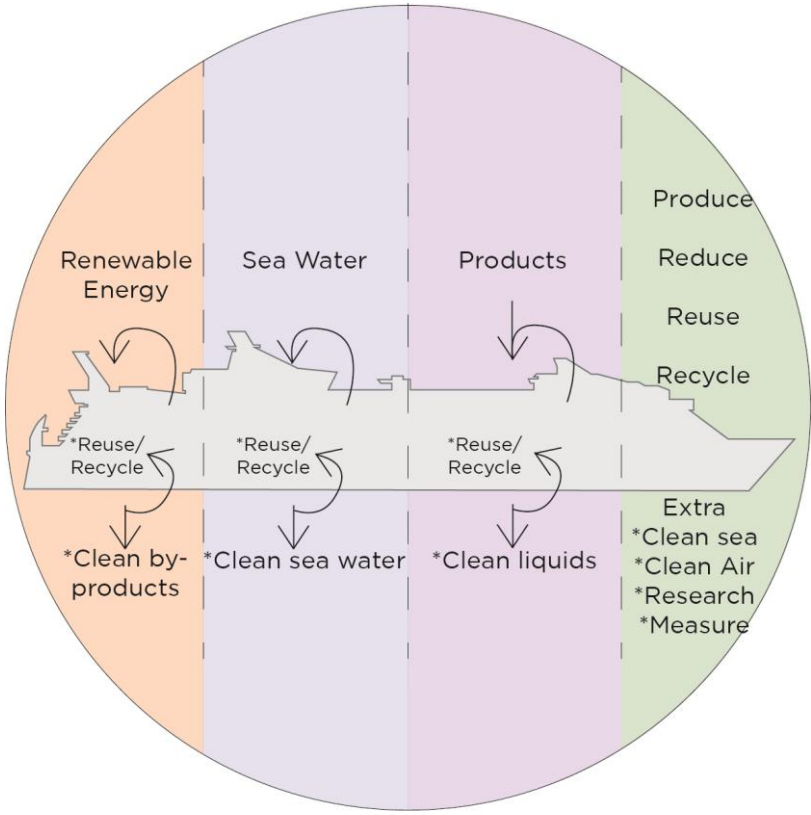




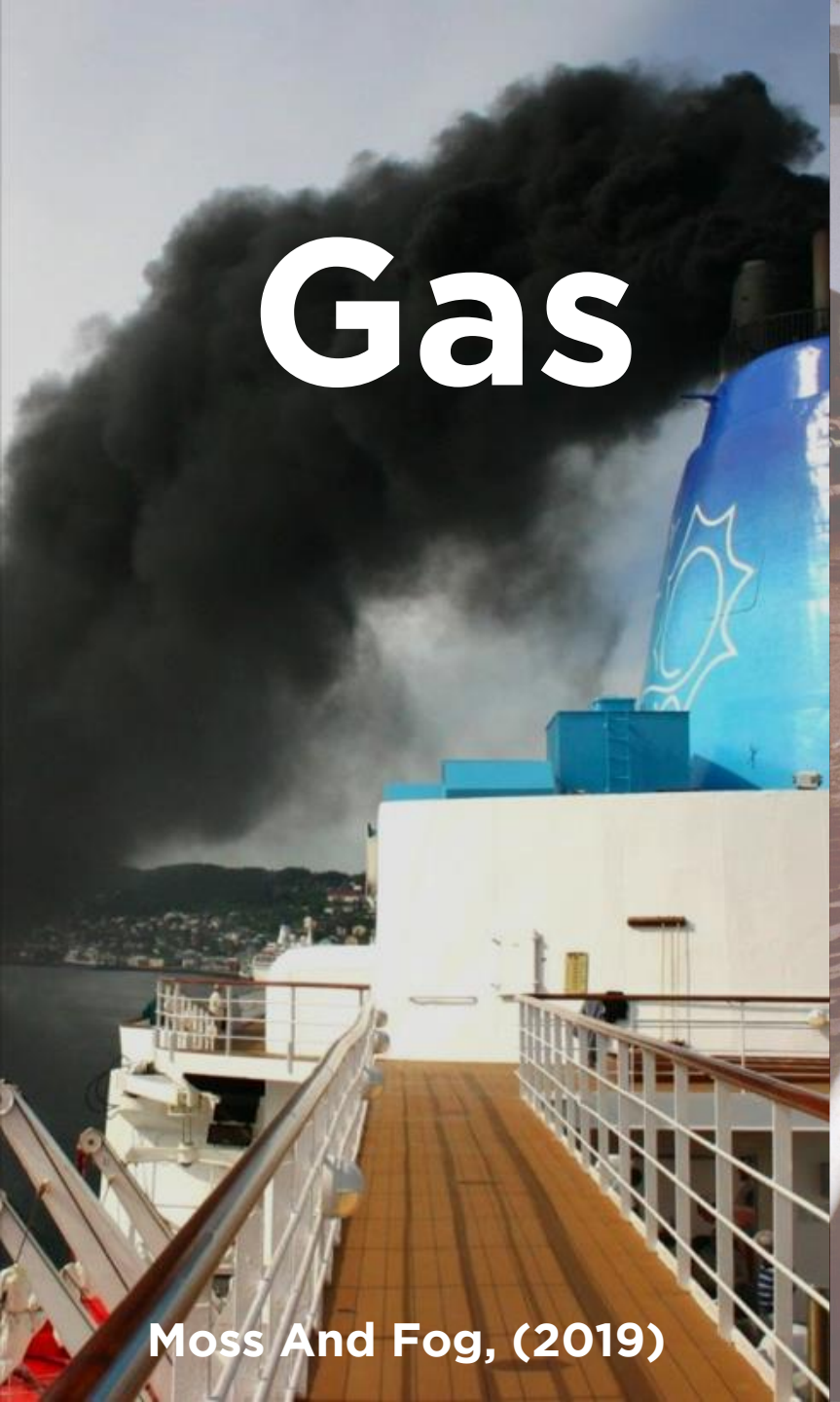
Roadmap A



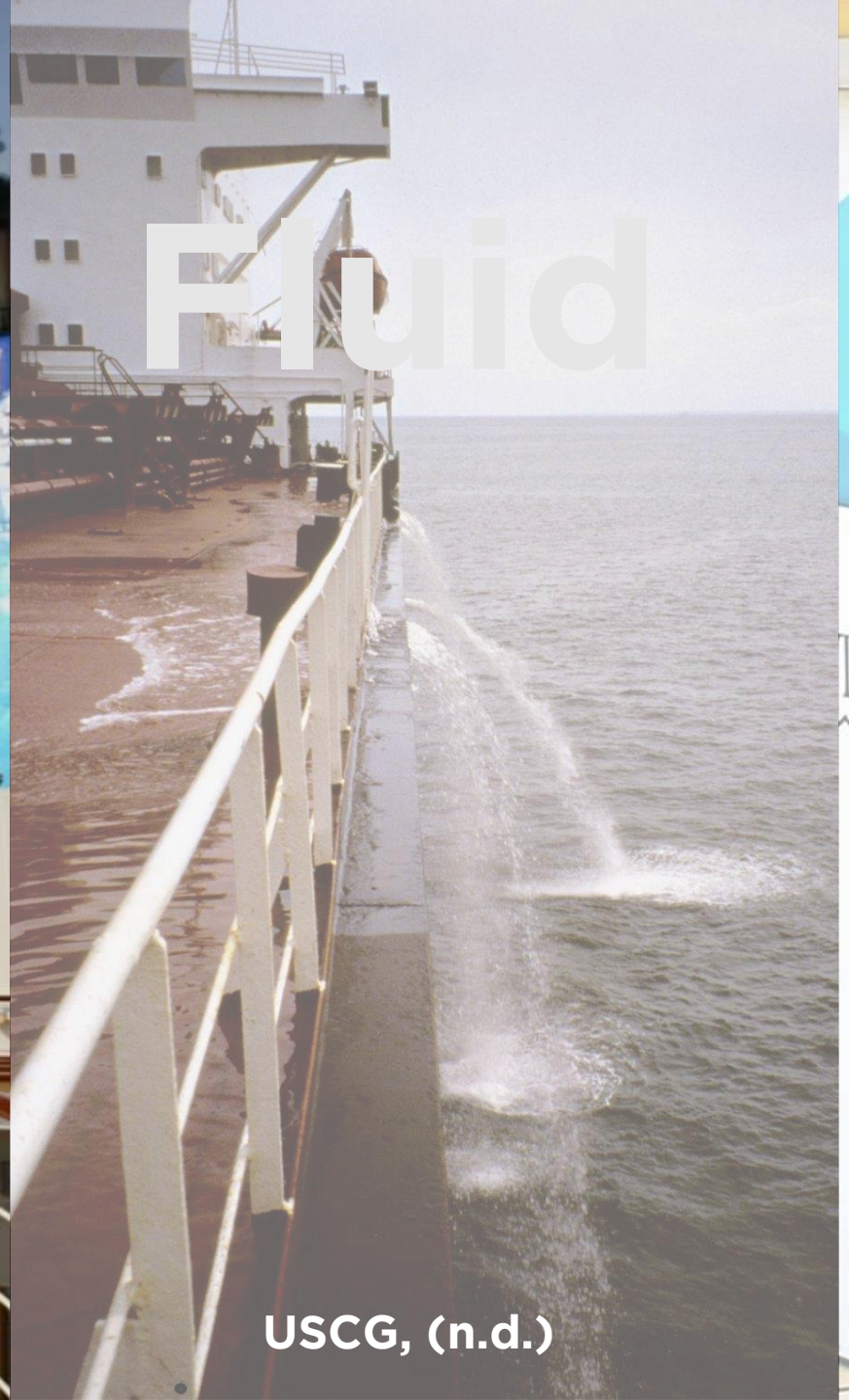
Roadmap B



Roadmap C



Moss And Fog, (2019)



USCG, (n.d.)

Less Haines, (n.d.)

	Hydrogen	Methanol	Bio-diesel	Dimethyl ether	Biogas	Renewable Energy Ship	Renewable Energy Island
Fuel Cell							
Dual Fuel Engine							
Combustion Engine							

Now | Near future | Late future

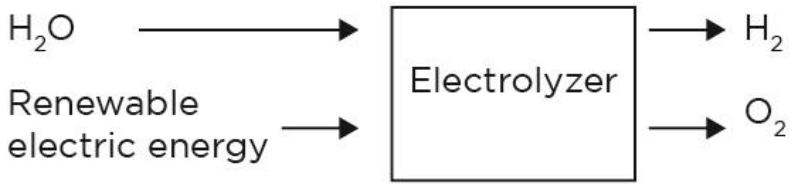
Retrofit

- Combustion engine -> Biodiesel/Dimethyl ether
  -> Methanol
- Dual Fuel engine -> Methanol

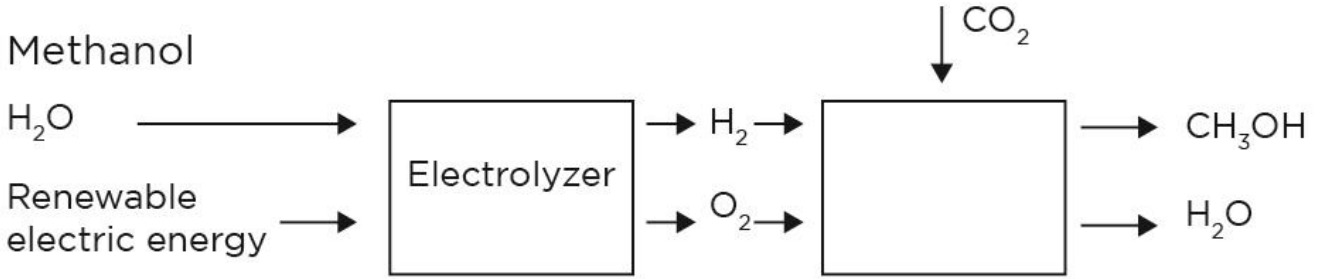
Newly Build

- Fuel Cell -> Hydrogen

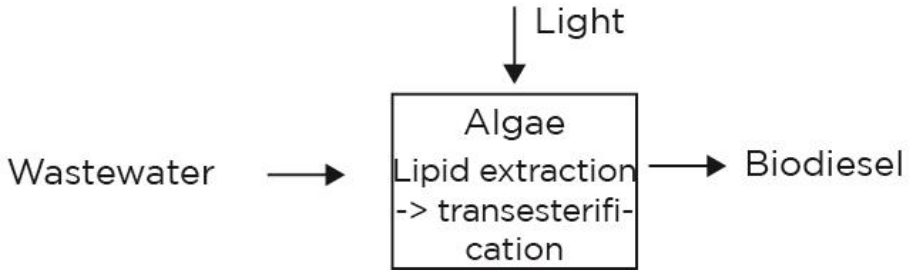
Hydrogen



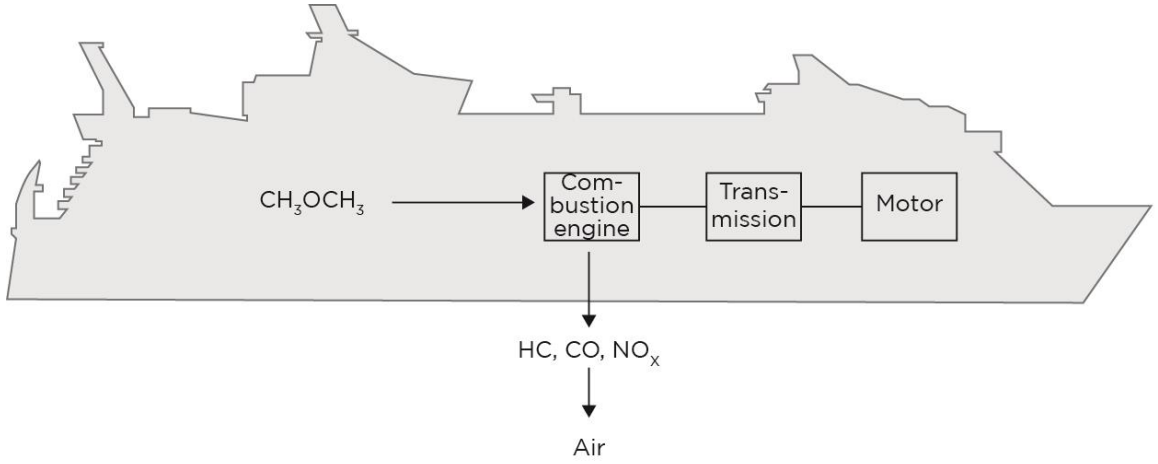
Methanol



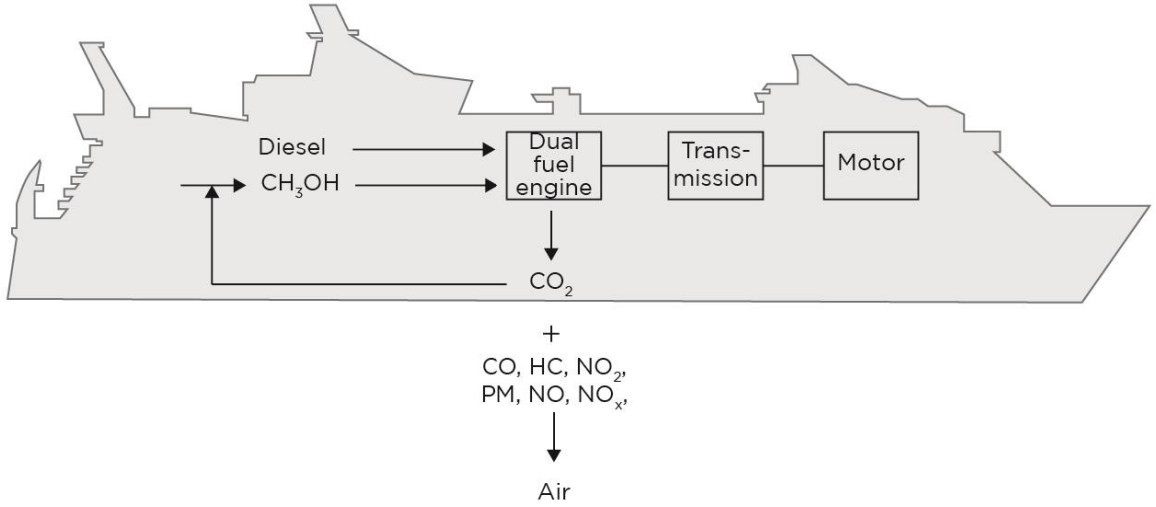
Biodiesel - Onboard



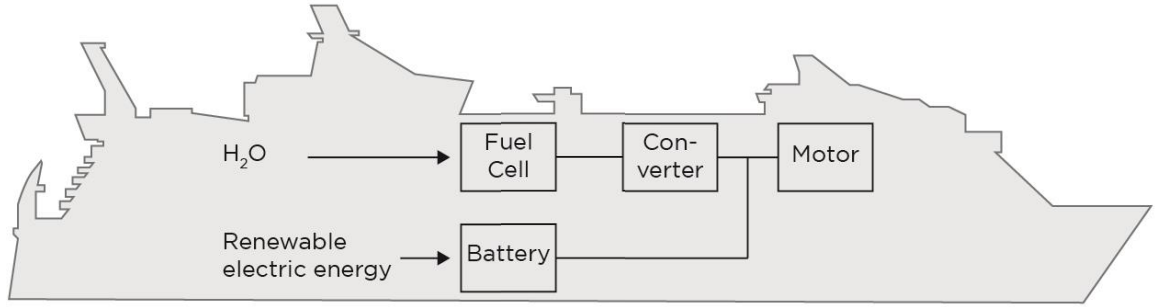
Dimethyl ether



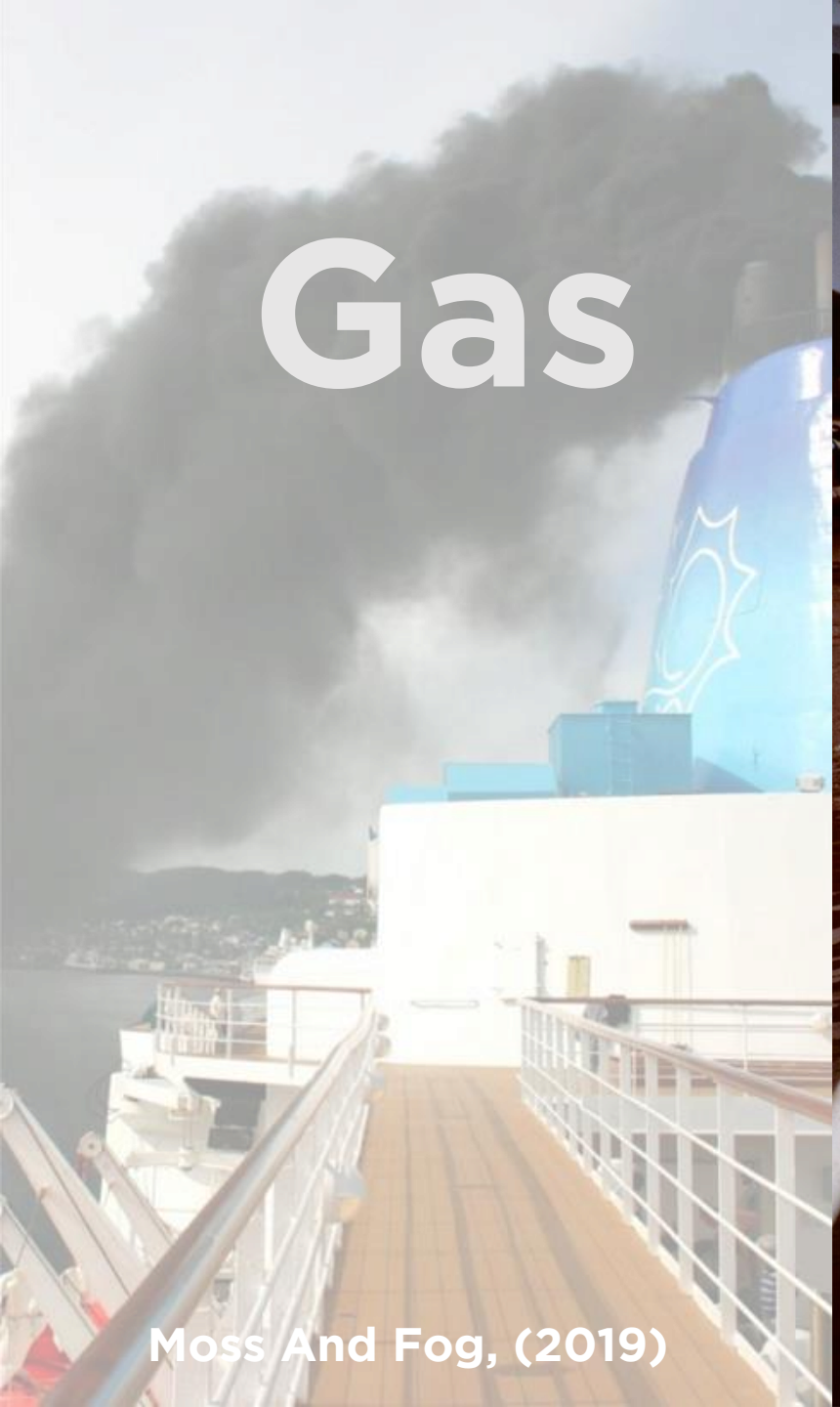
Combustion engine



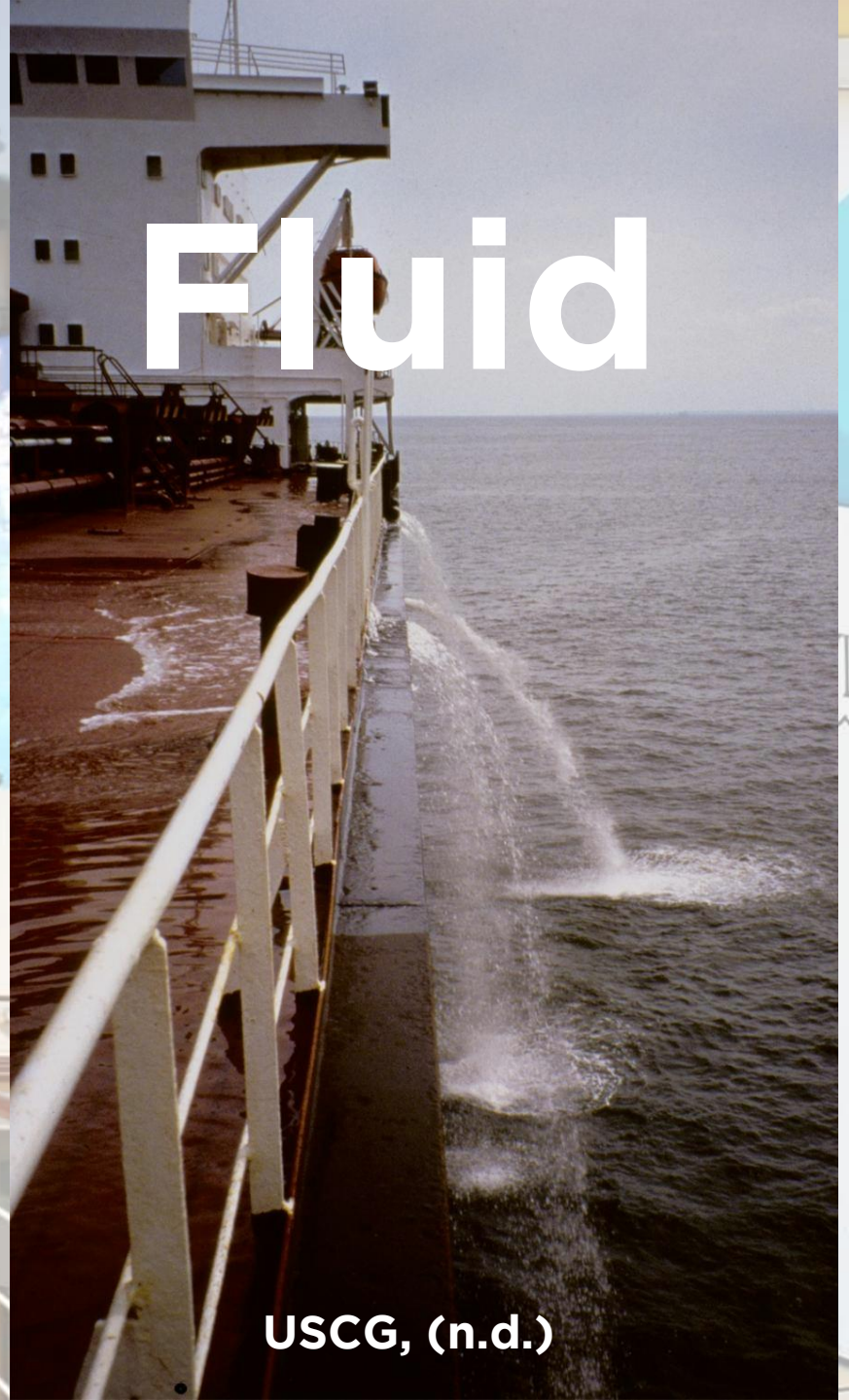
Dual Fuel engine



Fuel Cell

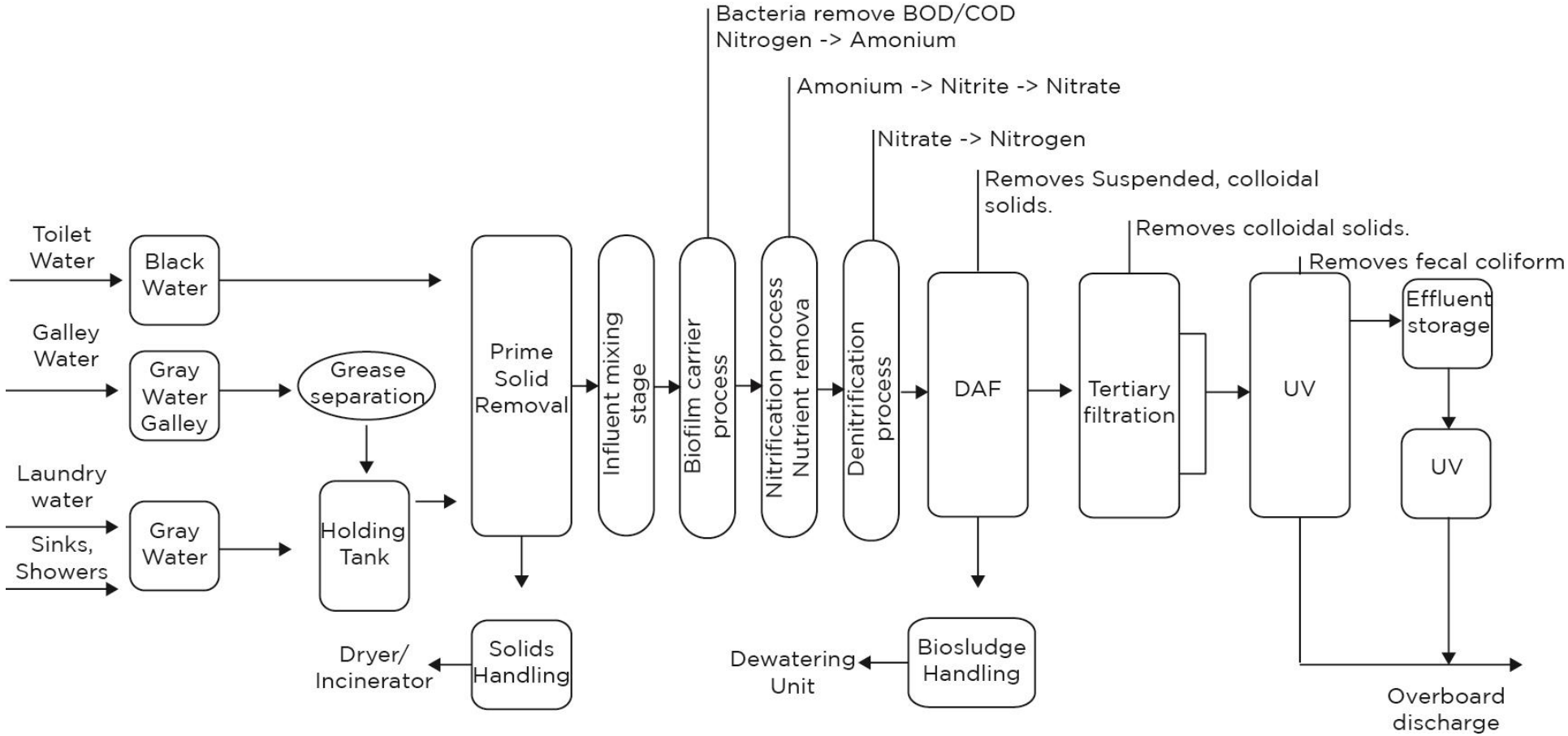


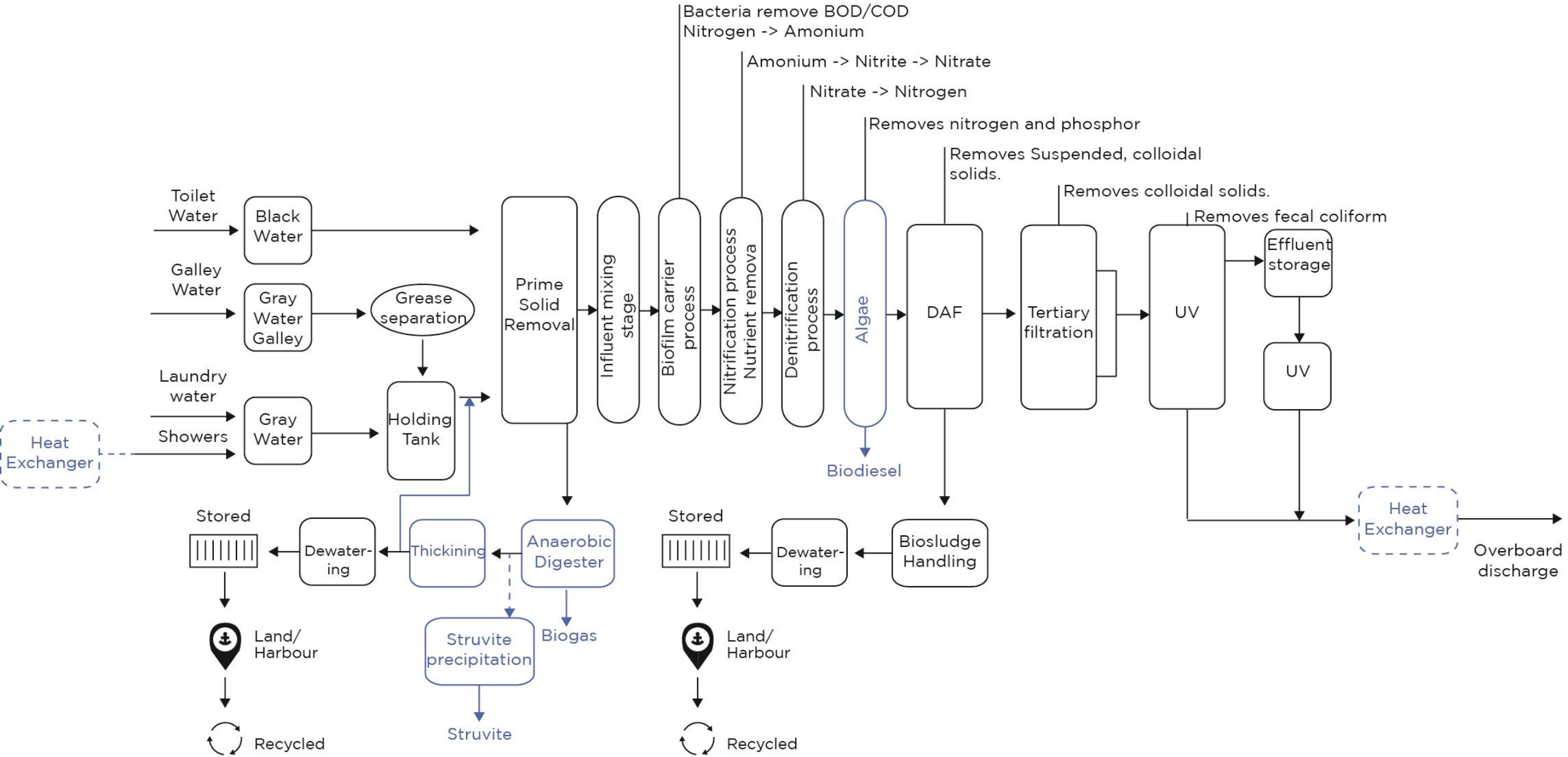
Moss And Fog, (2019)

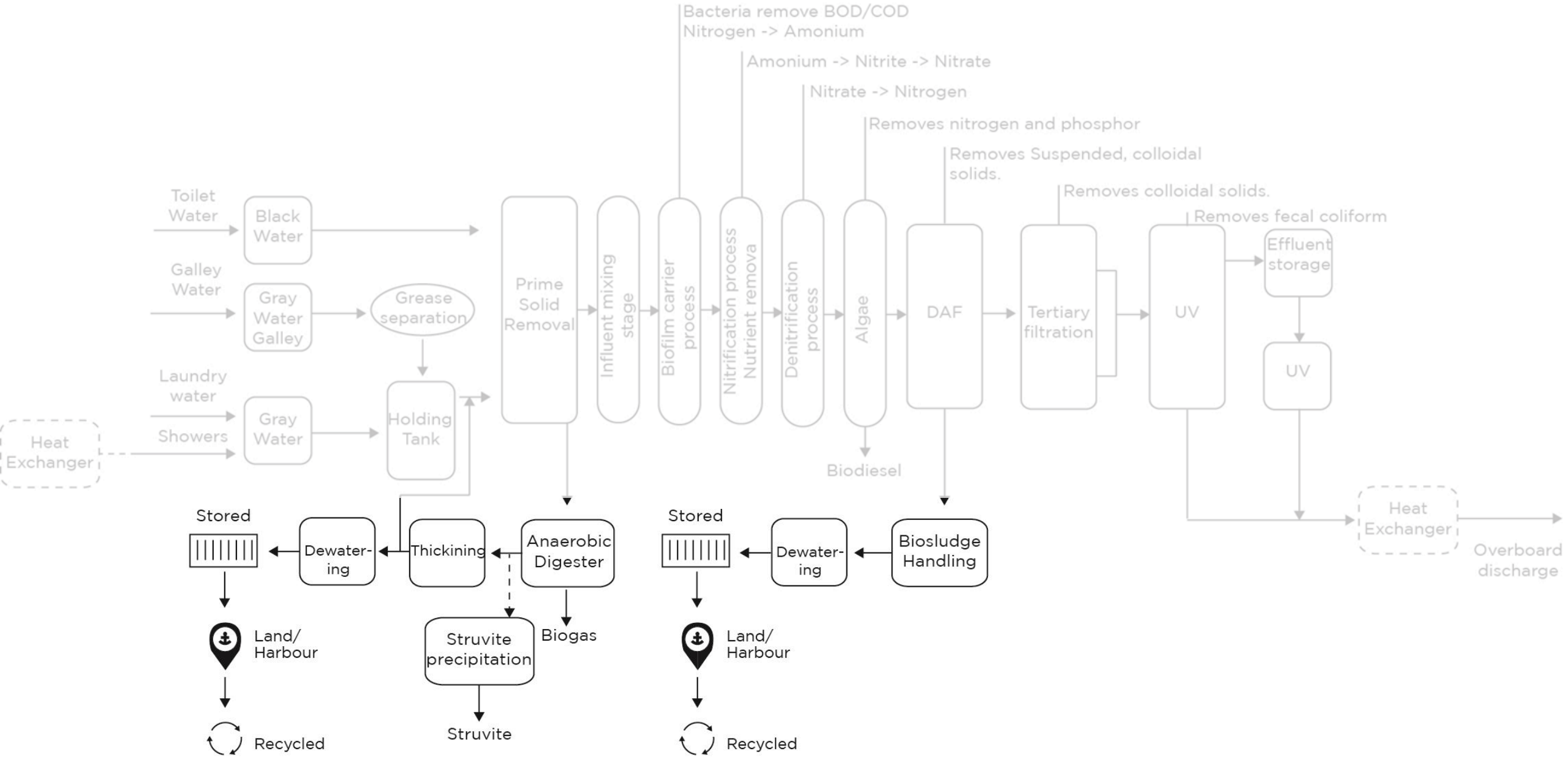


USCG, (n.d.)

Less Haines, (n.d.)


Bacteria remove BOD/COD
Nitrogen -> Amonium
Amonium -> Nitrite -> Nitrate
Nitrate -> Nitrogen
Removes Suspended, colloidal solids.
Removes colloidal solids.
Removes fecal coliform
Toilet Water
Black Water
Galley Water
Gray Water Galley
Grease separation
Laundry water
Sinks, Showers
Gray Water
Holding Tank
Prime Solid Removal
Influent mixing stage
Biofilm carrier process
Nitrification process Nutrient remova
Denitrification process
DAF
Tertiary filtration
UV
Effluent storage
UV
Solids Handling
Dryer/ Incinerator
Biosludge Handling
Dewatering Unit
Overboard discharge


Bacteria remove BOD/COD
Nitrogen -> Amonium
Amonium -> Nitrite -> Nitrate
Nitrate -> Nitrogen
Removes nitrogen and phosphor
Removes Suspended, colloidal solids.
Removes colloidal solids.
Removes fecal coliform
Toilet Water
Black Water
Galley Water
Gray Water Galley
Grease separation
Laundry water
Showers
Gray Water
Heat Exchanger
Holding Tank
Prime Solid Removal
Influent mixing stage
Biofilm carrier process
Nitrification process Nutrient remova
Denitrification process
Algae
Biodiesel
DAF
Tertiary filtration
UV
Effluent storage
UV
Heat Exchanger
Overboard discharge
Stored
Dewater-ing
Thickining
Anaerobic Digester
Biogas
Struvite precipitation
Struvite
Land/ Harbour
Recycled
Stored
Dewater-ing
Biosludge Handling
Land/ Harbour
Recycled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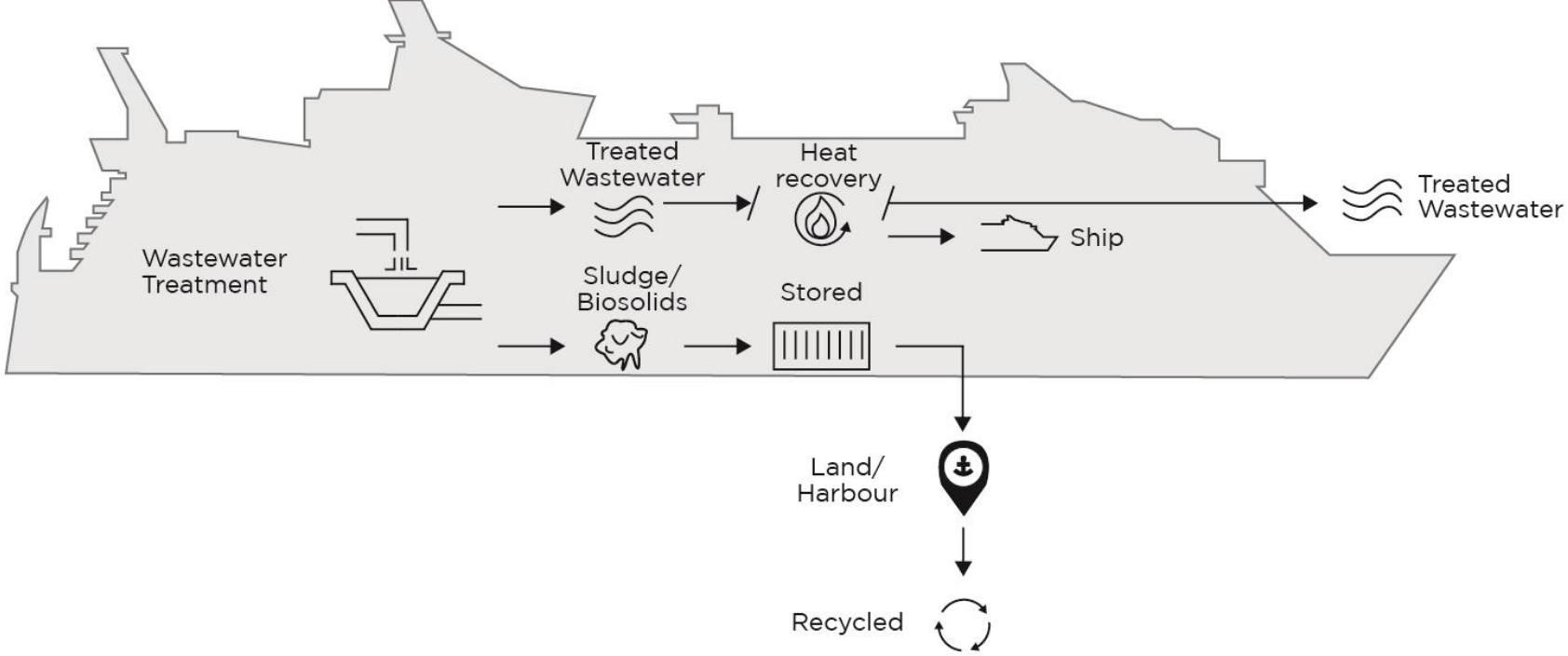
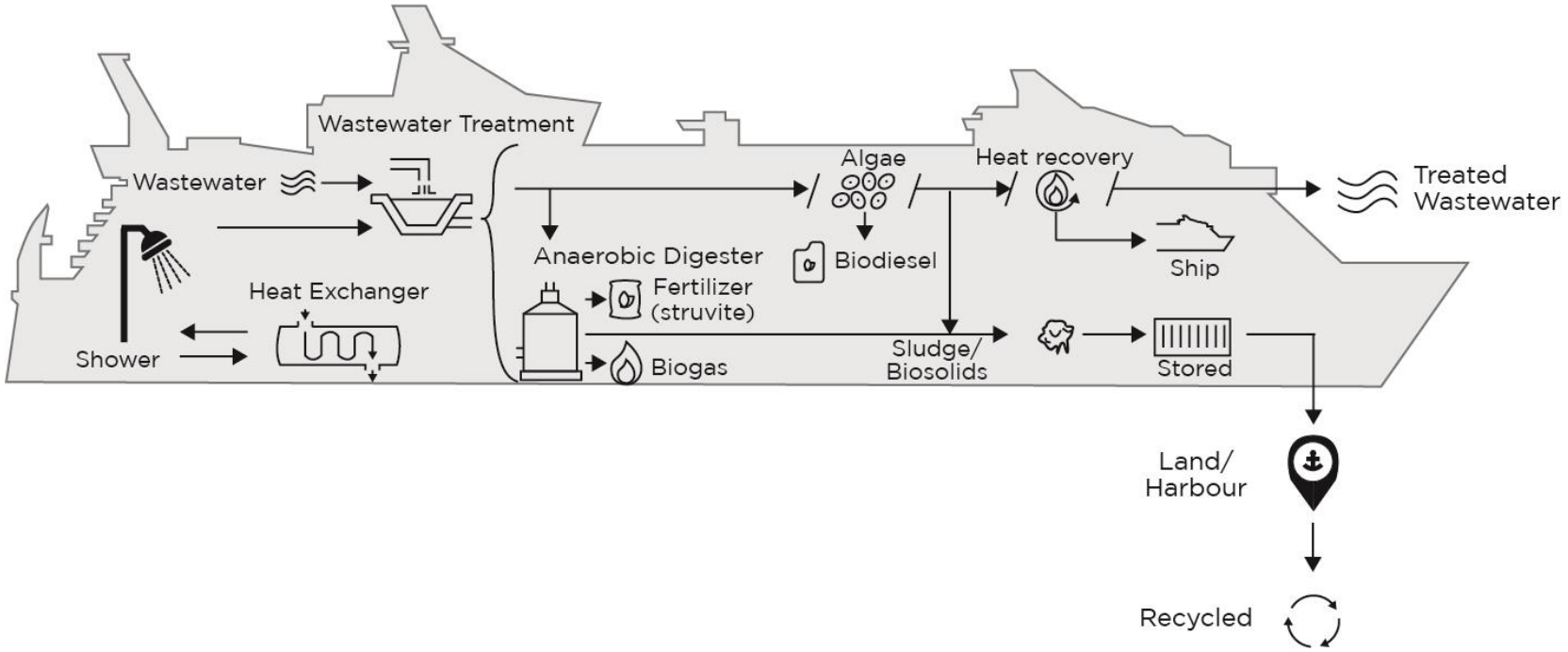
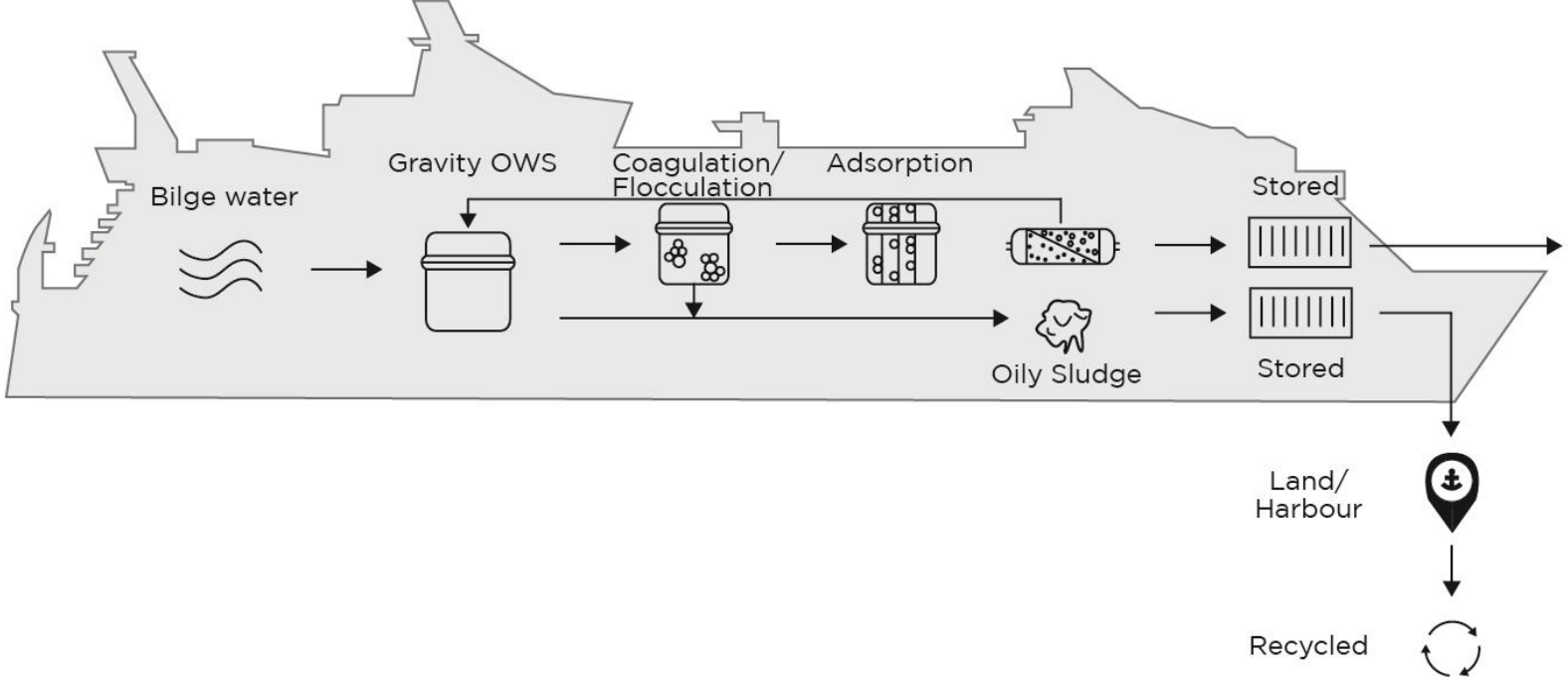
Anaerobic Digester
Biosludge Handling
Land/ Harbour
Struvite precipitation
Biogas
Struvite
Recycled



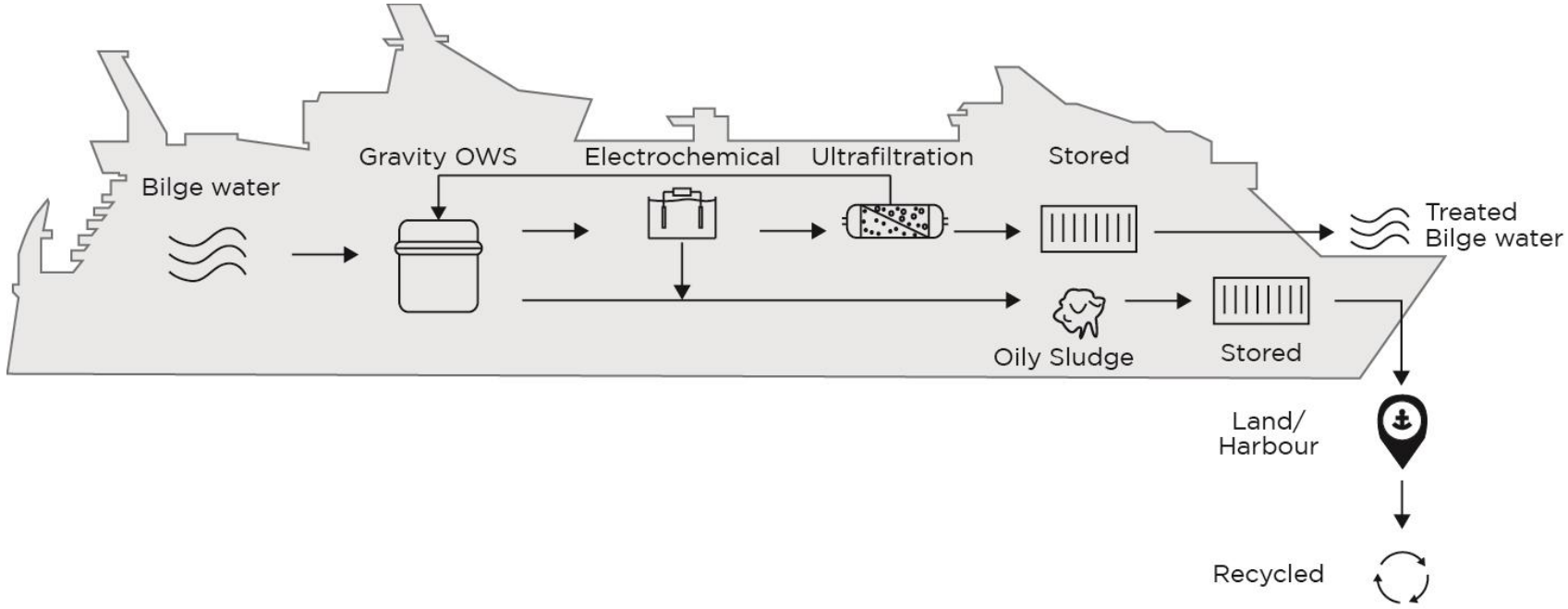
- Retrofit
  - Heat recovery black and grey water
  - Recycling biosolids and sludge



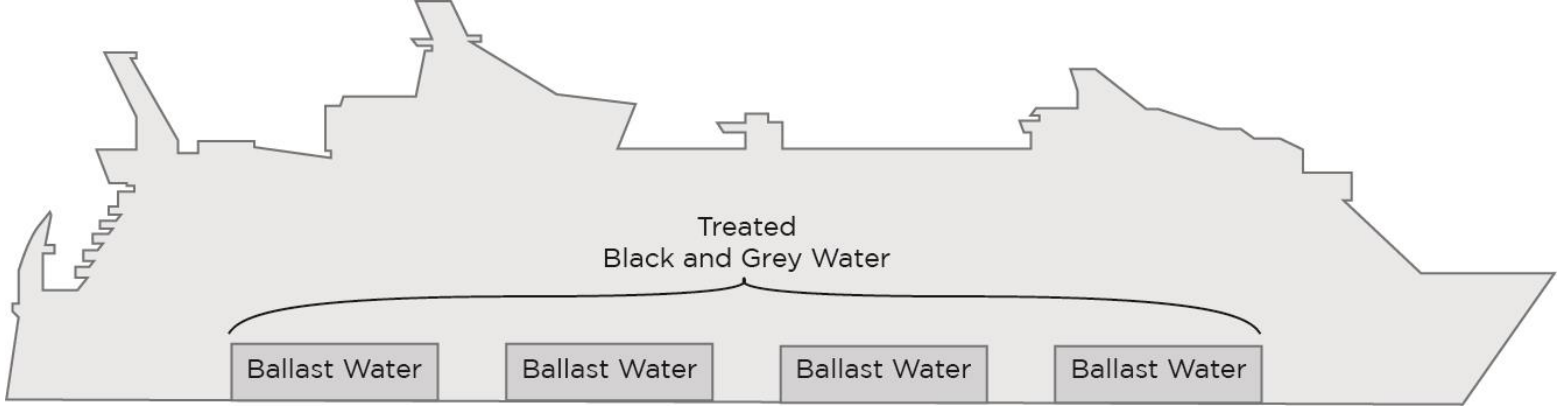
- Newly Build
  - Heat recovery black and grey water
  - Recycling biosolids and sludge
  - Heat exchanger shower
  - Anaerobic digester
  - Struvite recovery
  - Algae system



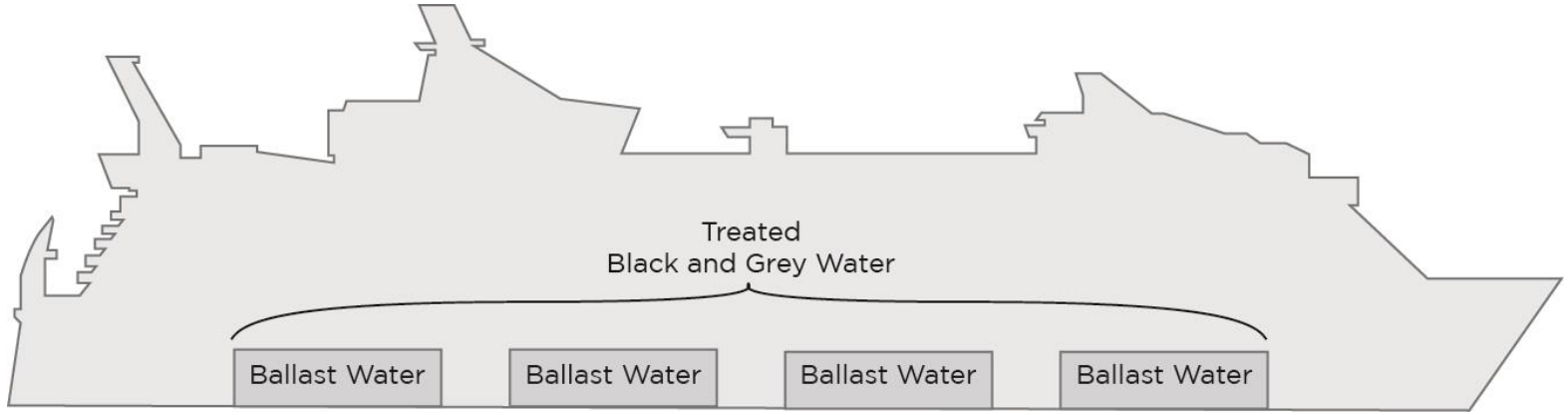
- Retrofit
  - Membrane treatment (Nanofiltration/ Reverse osmosis)
  - Recycling of oily sludge on land



- Newly Build
  - Electrochemical treatment
  - Recycling of oily sludge on land



- Retrofit
  - Treated black and grey water as ballast water

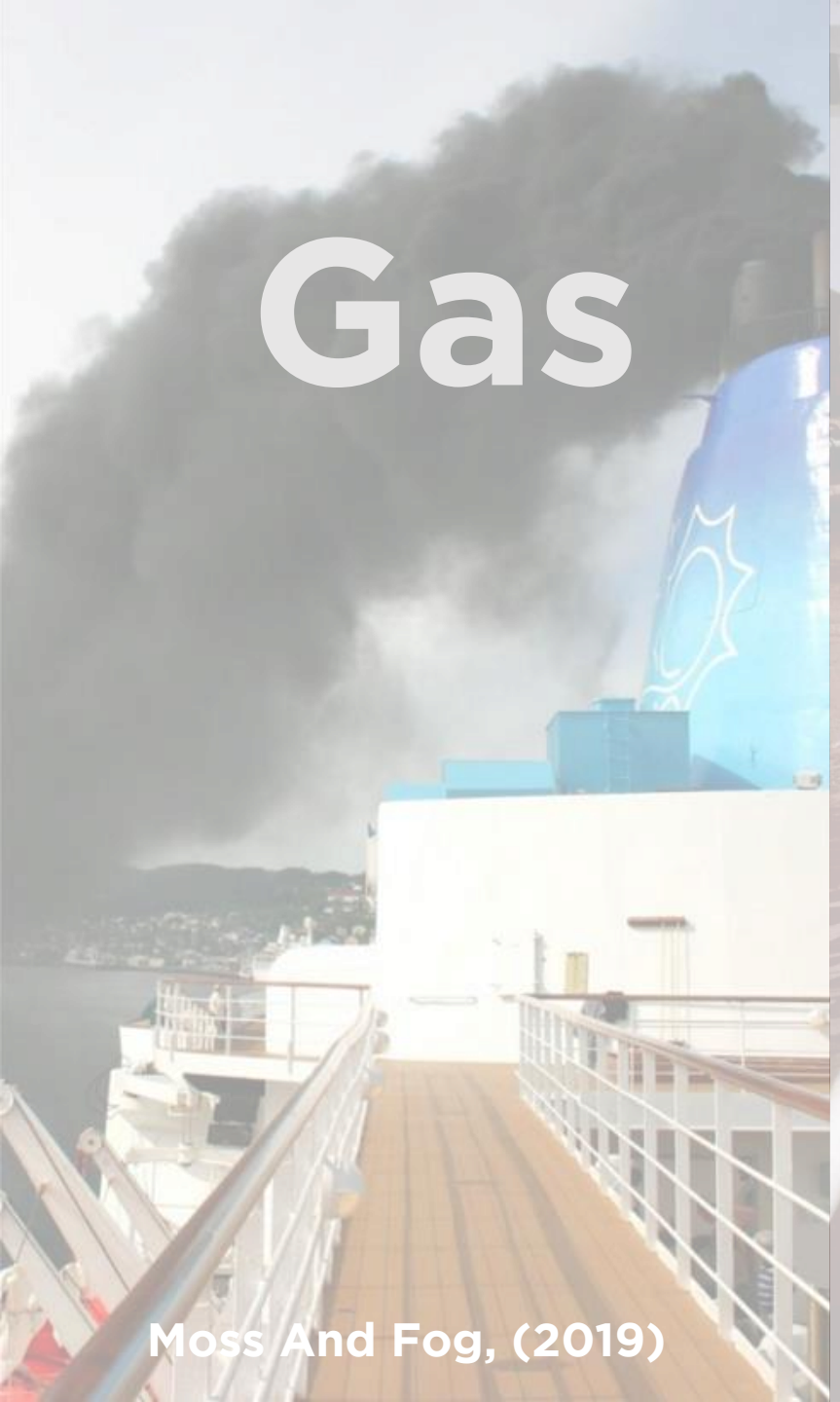


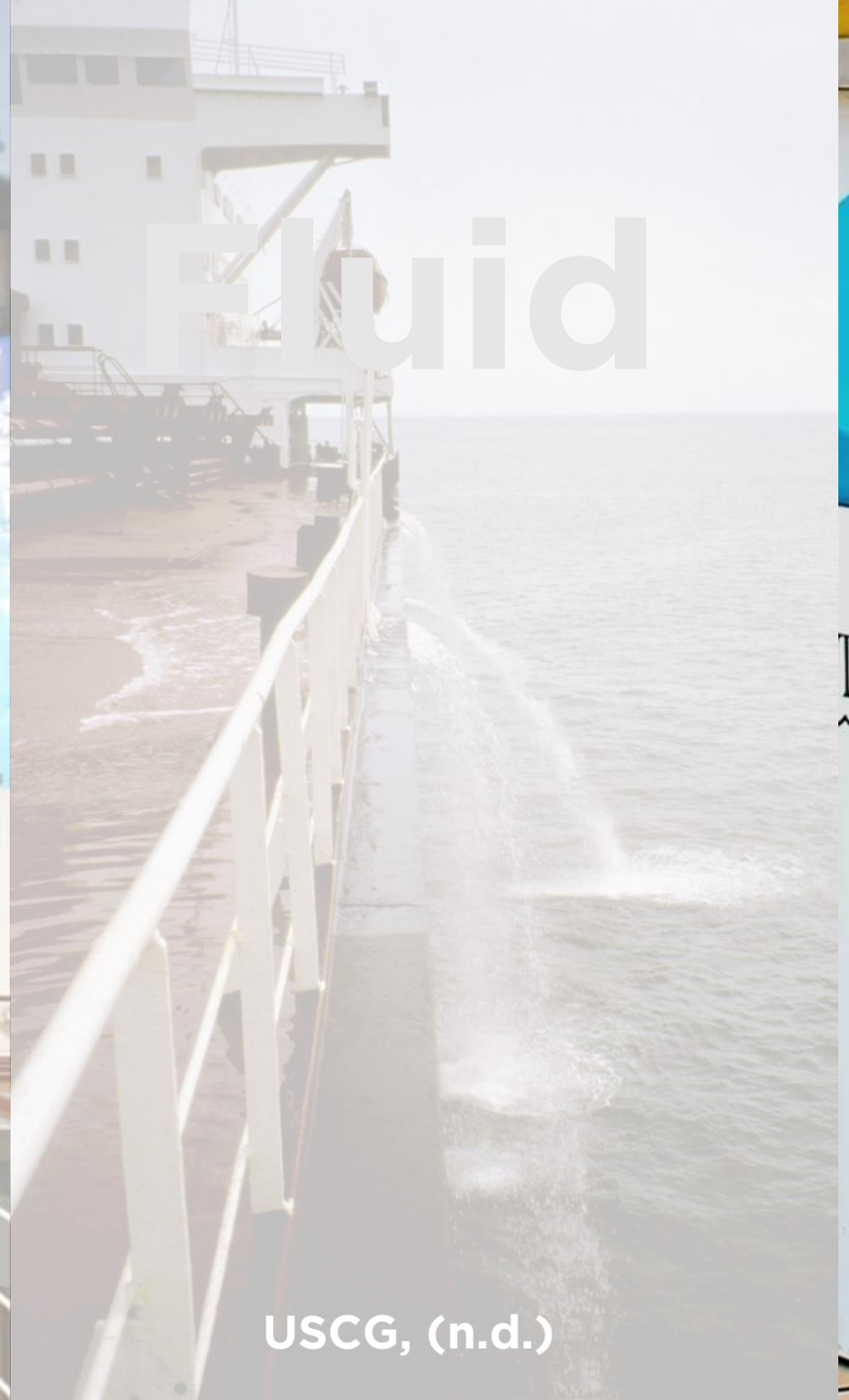
- Newly Build
  - Treated black and grey water as ballast water

Gas

Fluid

Solid

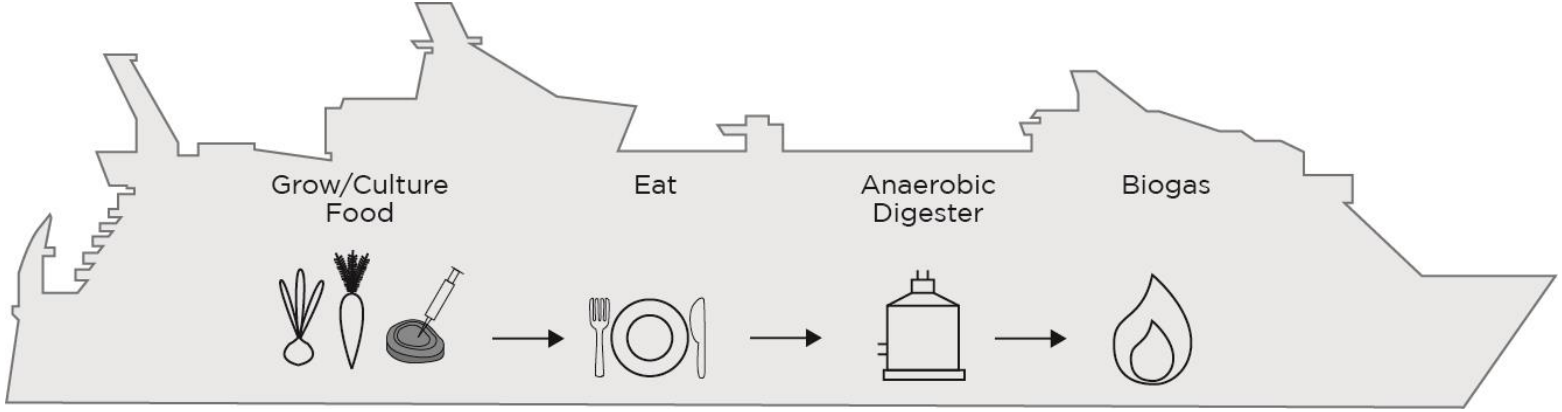




Moss And Fog, (2019)

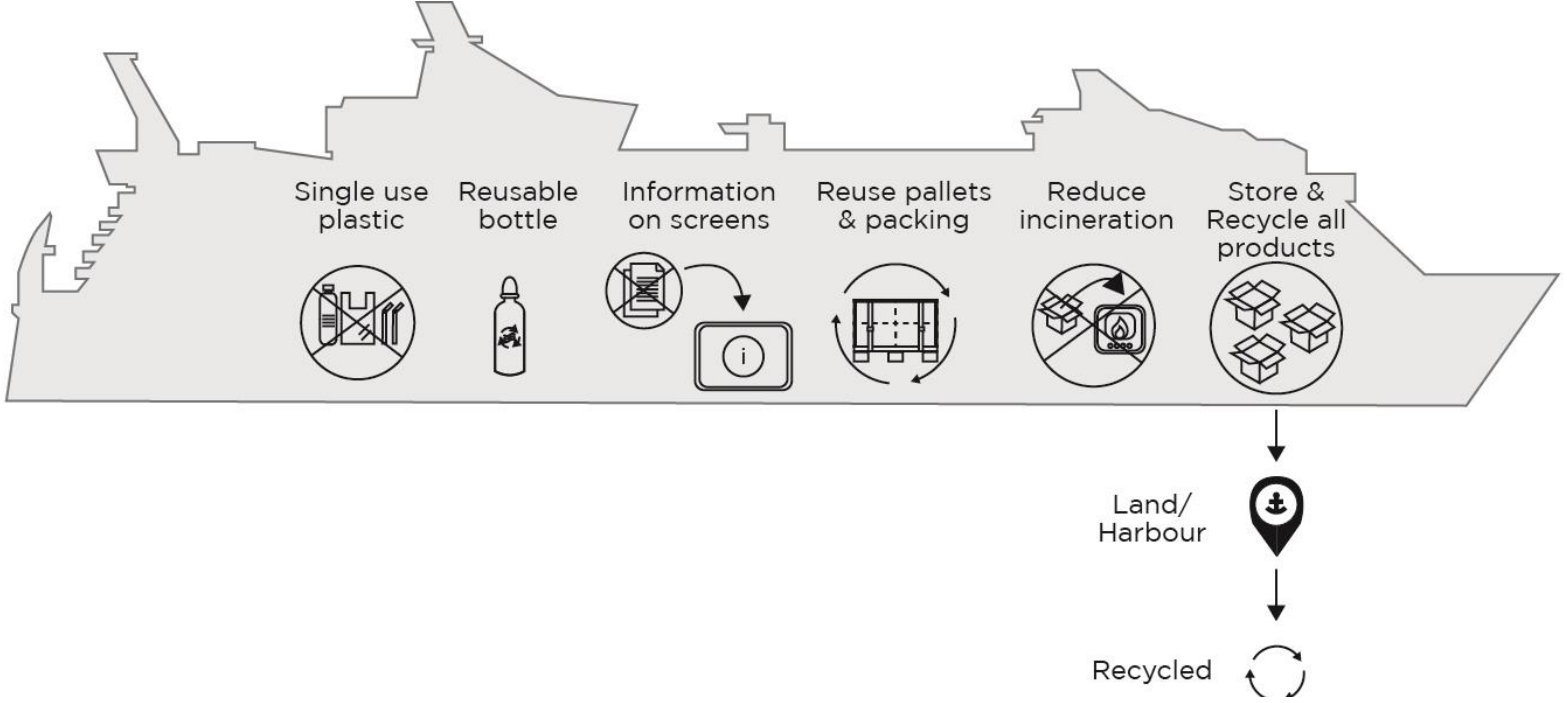
USCG, (n.d.)

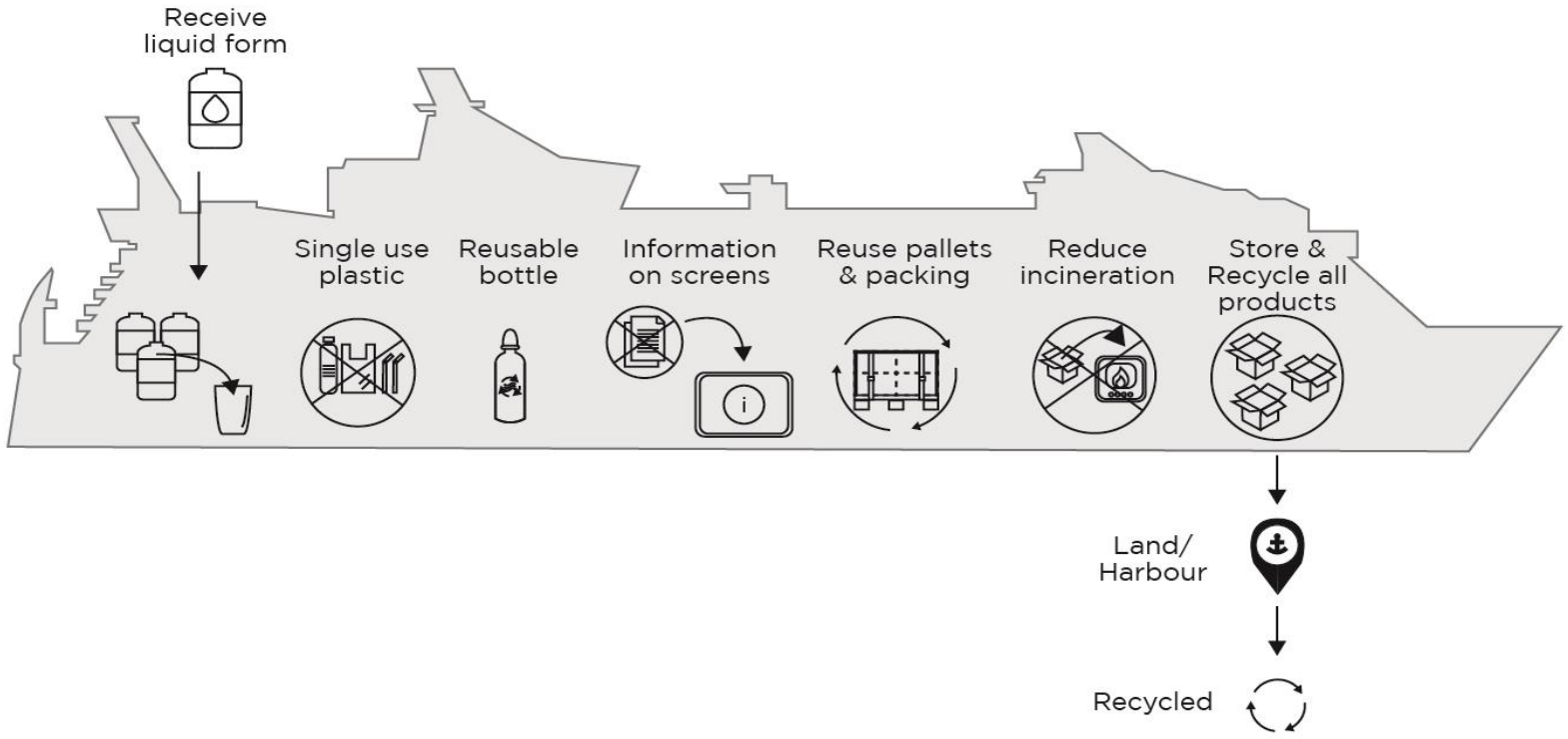
Less Haines, (n.d.)



Non-hazardous solid waste

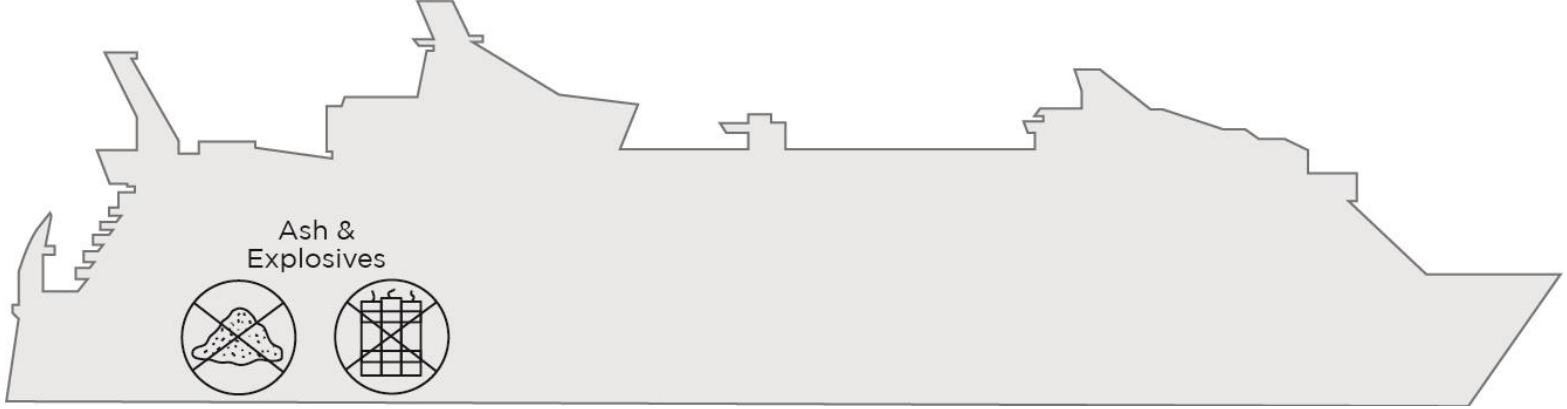
- Newly Build
  - Eliminate explosive use for pleasure
  - Prohibit the burning of hazardous waste
  - Install wet cleaning facilities





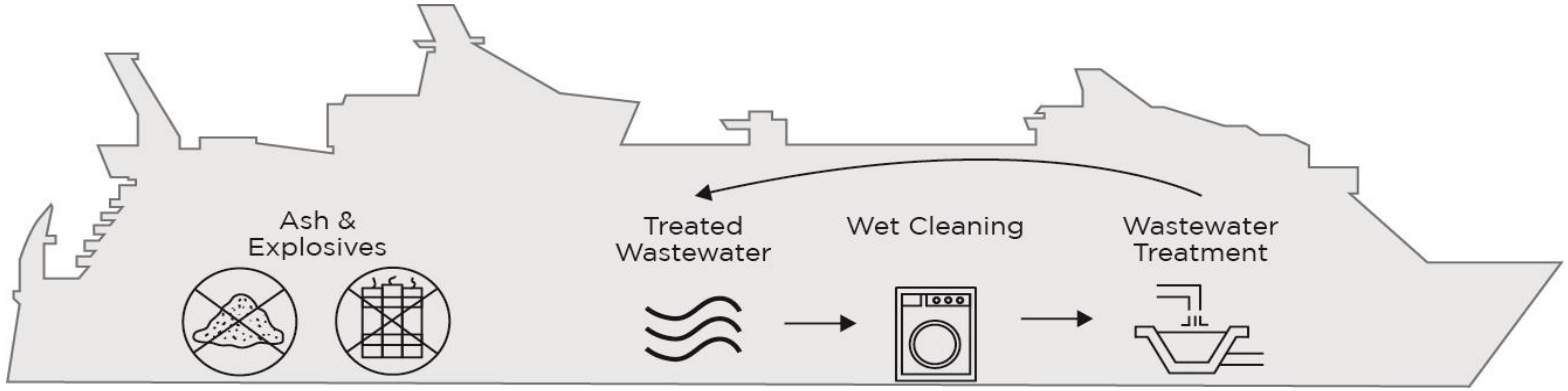
- Retrofit
  - Eliminate single use plastic
  - Give a reusable plastic bottle to every passenger onboard
  - Eliminated all the paper information, show everything on screens.
  - Reuse packaging and pallets multiple times
  - Recycle the products instead of incineration.
  - Dispose waste to land where it can be recycled.

- Newly Build
  - Receive all the drinks in liquid form and store it in tanks. This eliminates the need for single used glass, plastic and aluminium bottles.



Hazardous solid waste

- Retrofit
  - Eliminate explosive use for pleasure
  - Prohibit the burning of hazardous waste



Hazardous solid waste

- Newly Build
  - Eliminate explosive use for pleasure
  - Prohibit the burning of hazardous waste
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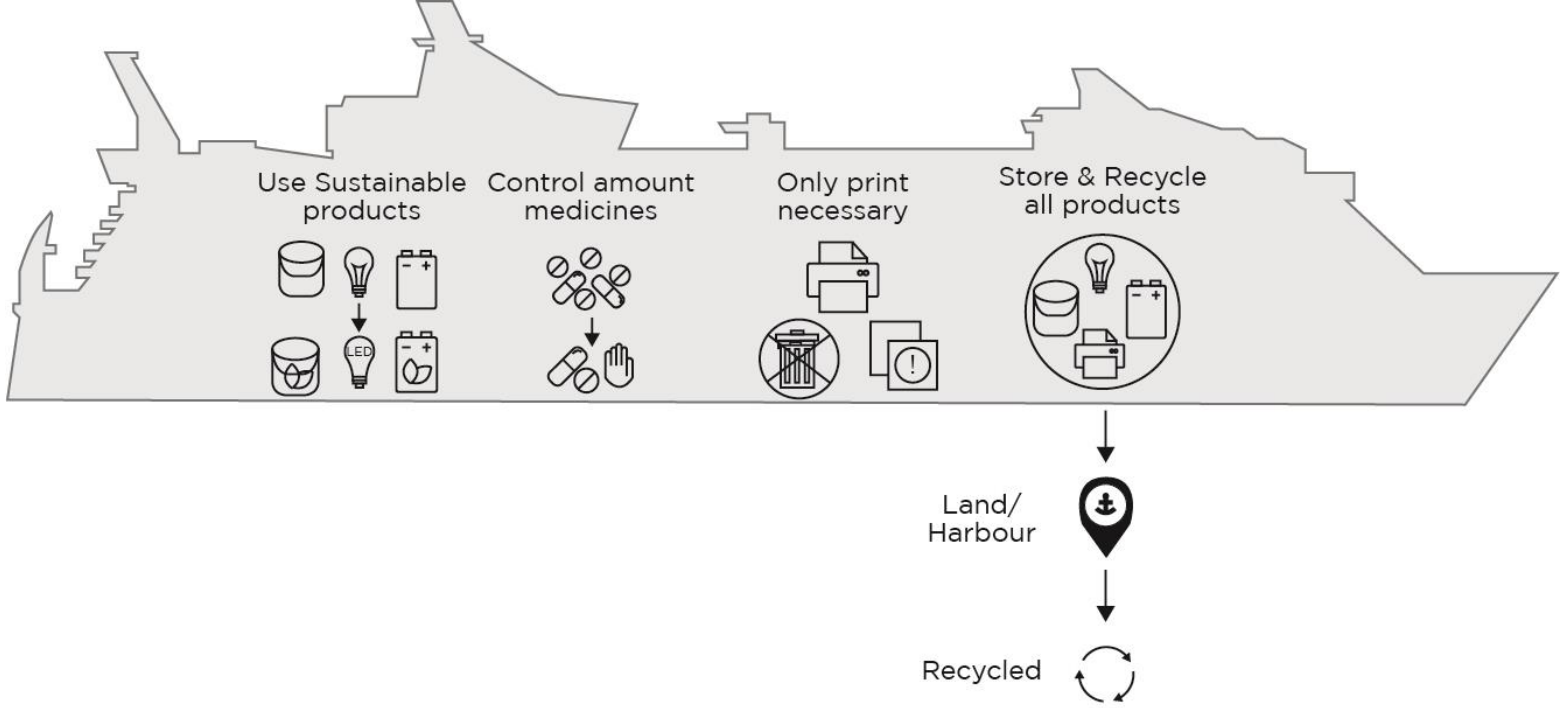
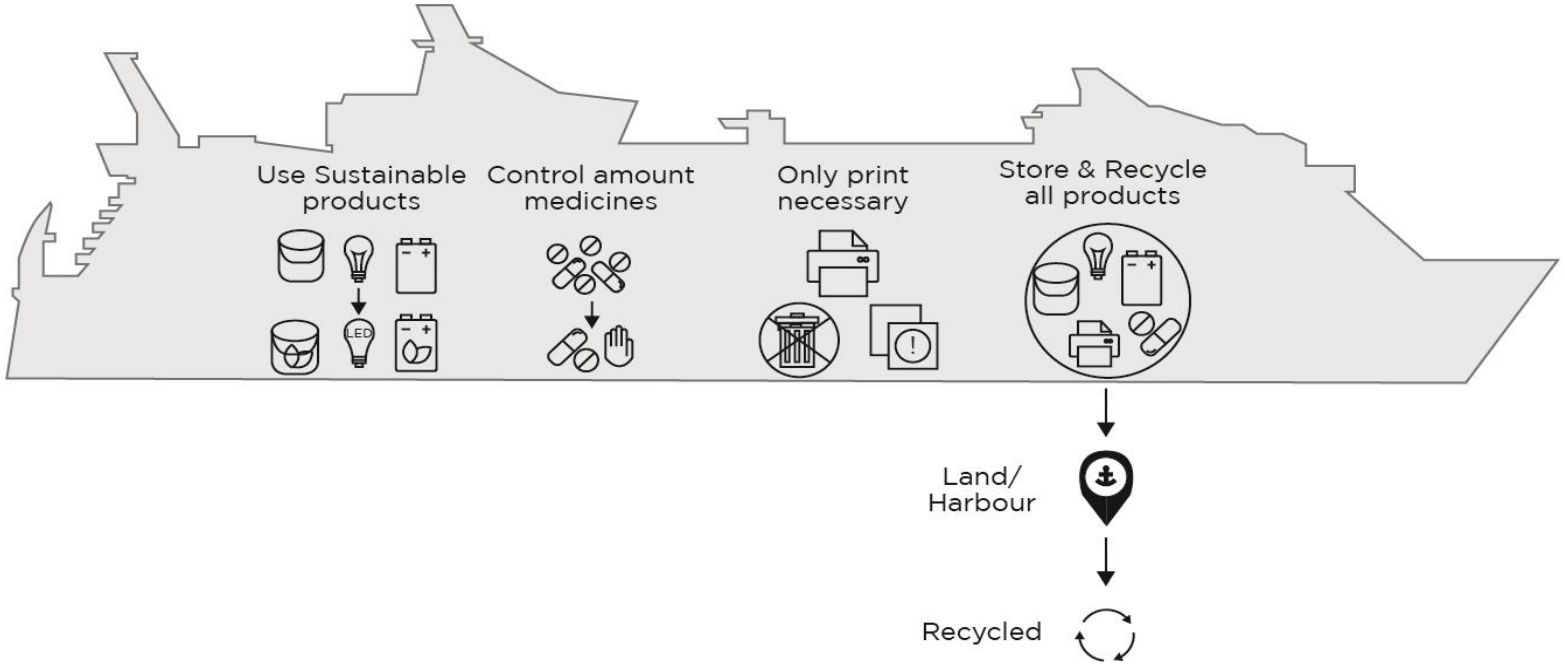
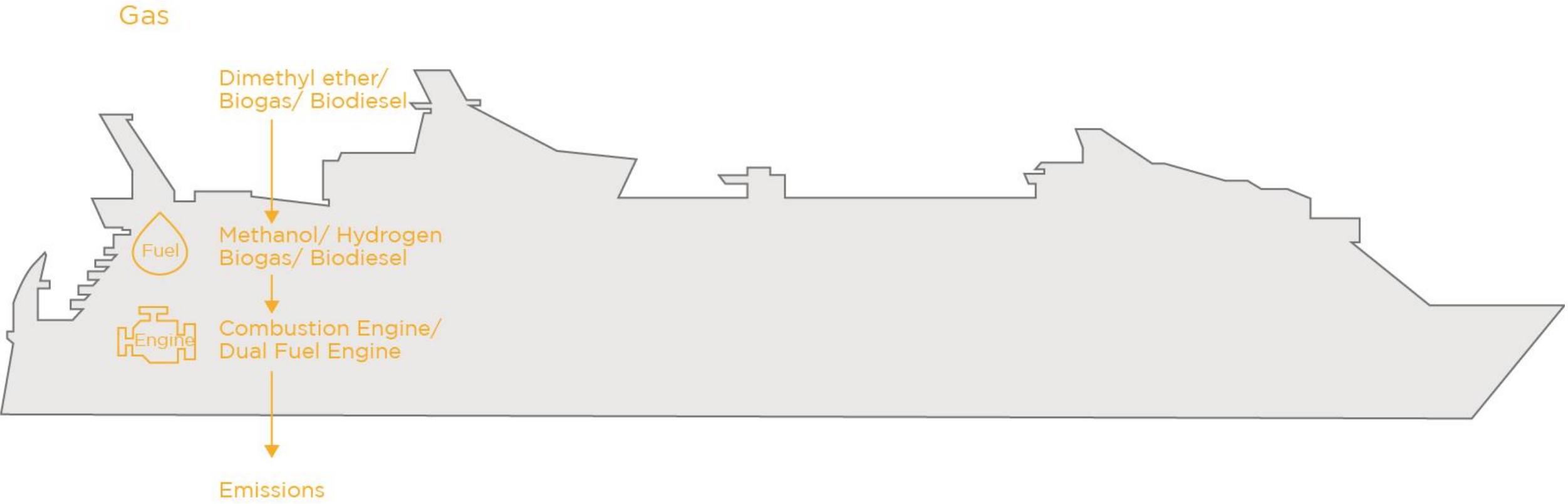




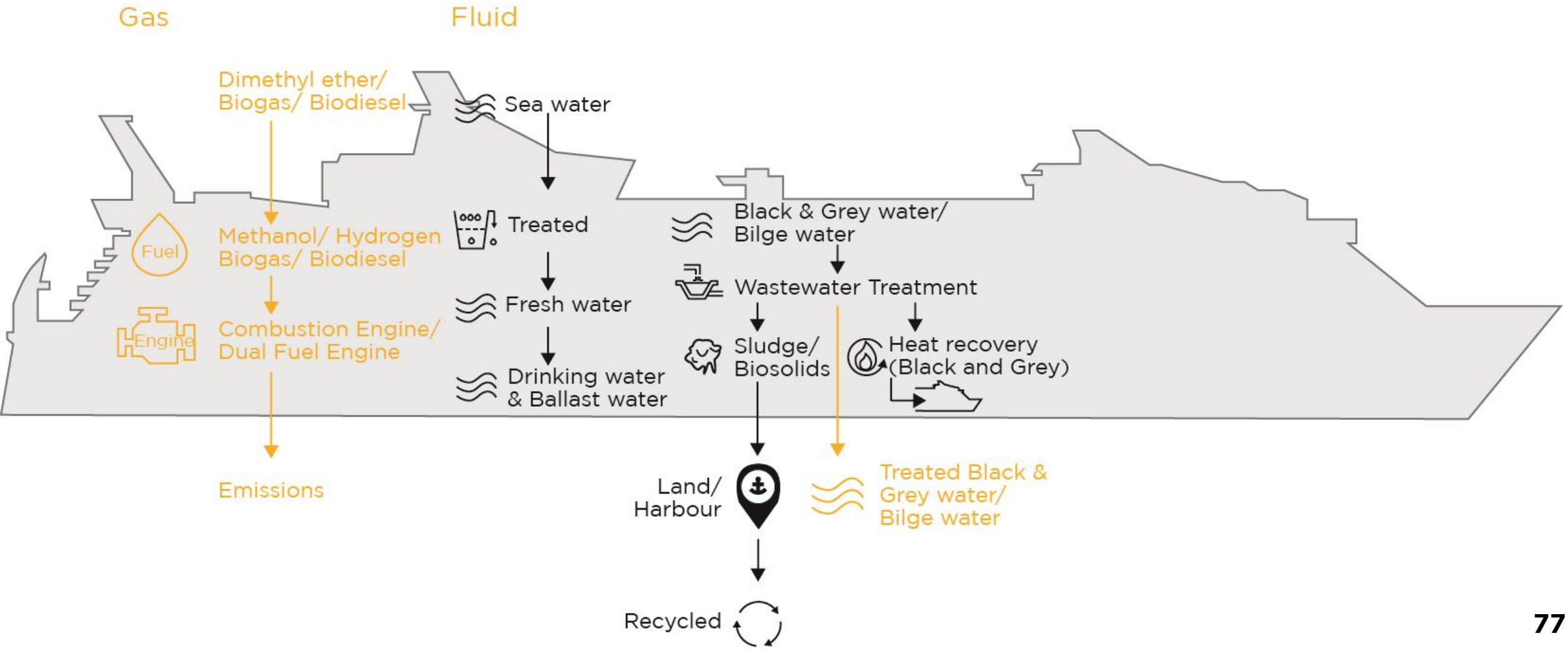
- Retrofit
  - Replace the paints, lights, and batteries with sustainable alternatives.
  - Only buy the needed amount of pharmaceuticals
  - Only print when a hardcopy is needed and pictures are bought.
  - Dispose of paint waste, lights, batteries and photo, and printing waste to land where it can be recycled.

- Newly Build
  - Recycling of medical waste

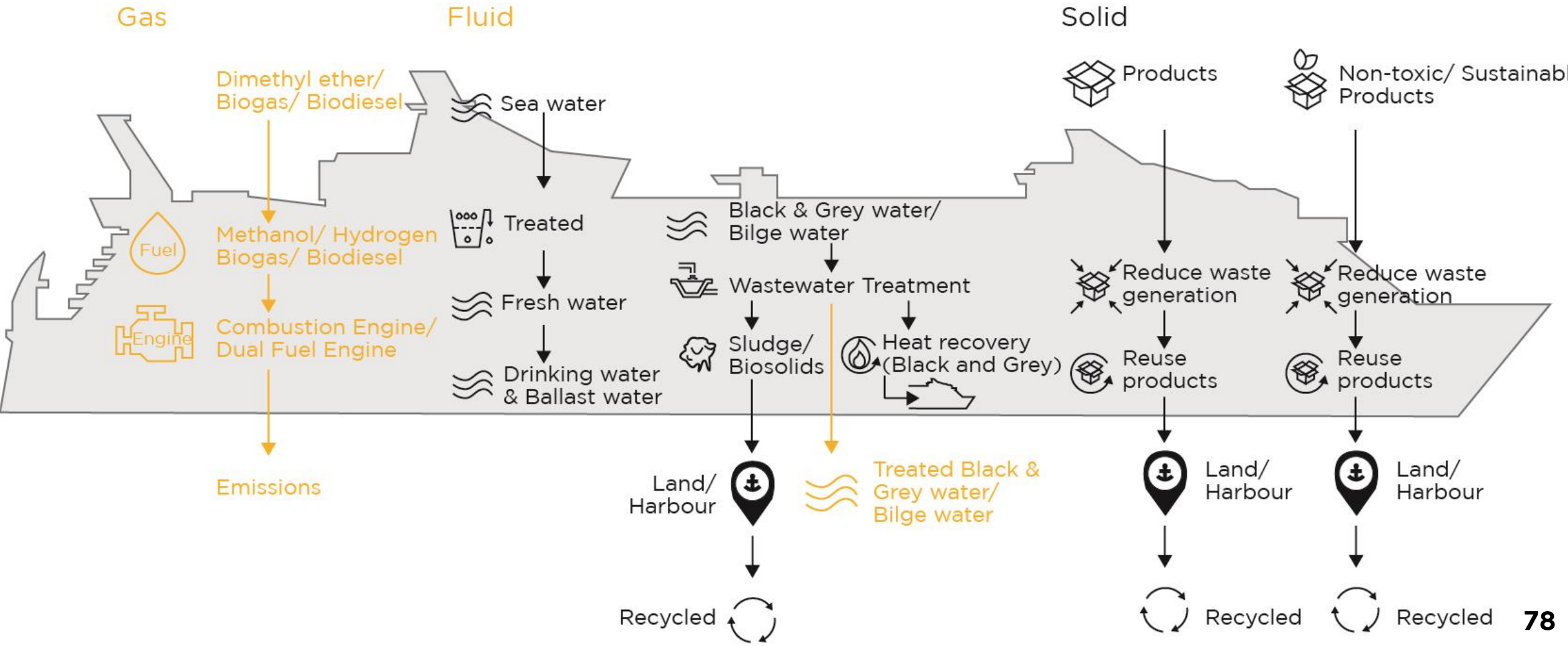
Combination - Retrofit



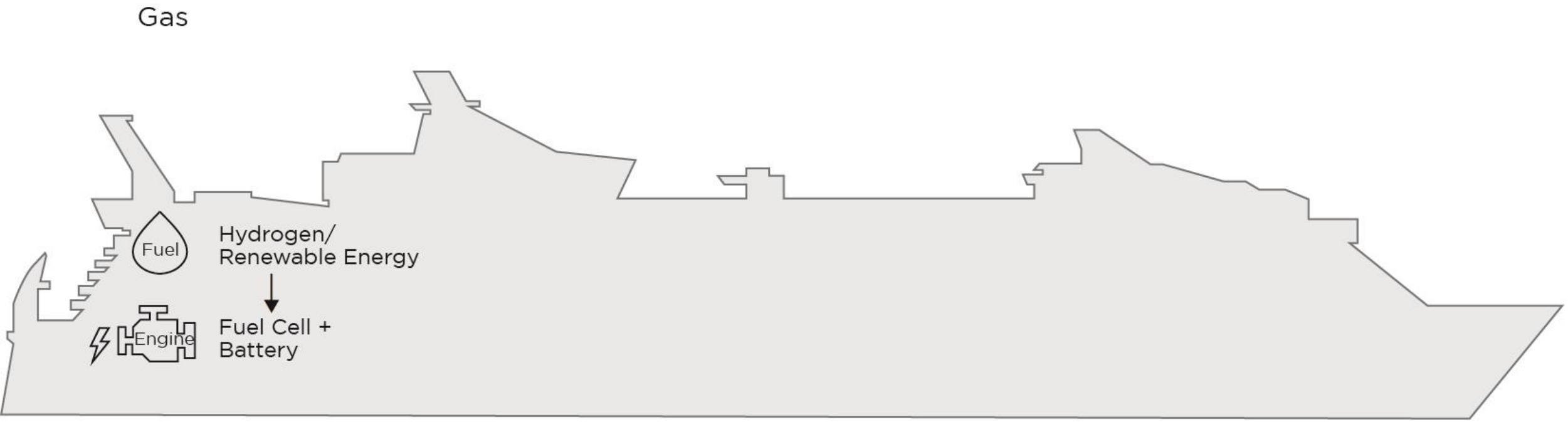
Combination - Retrofit



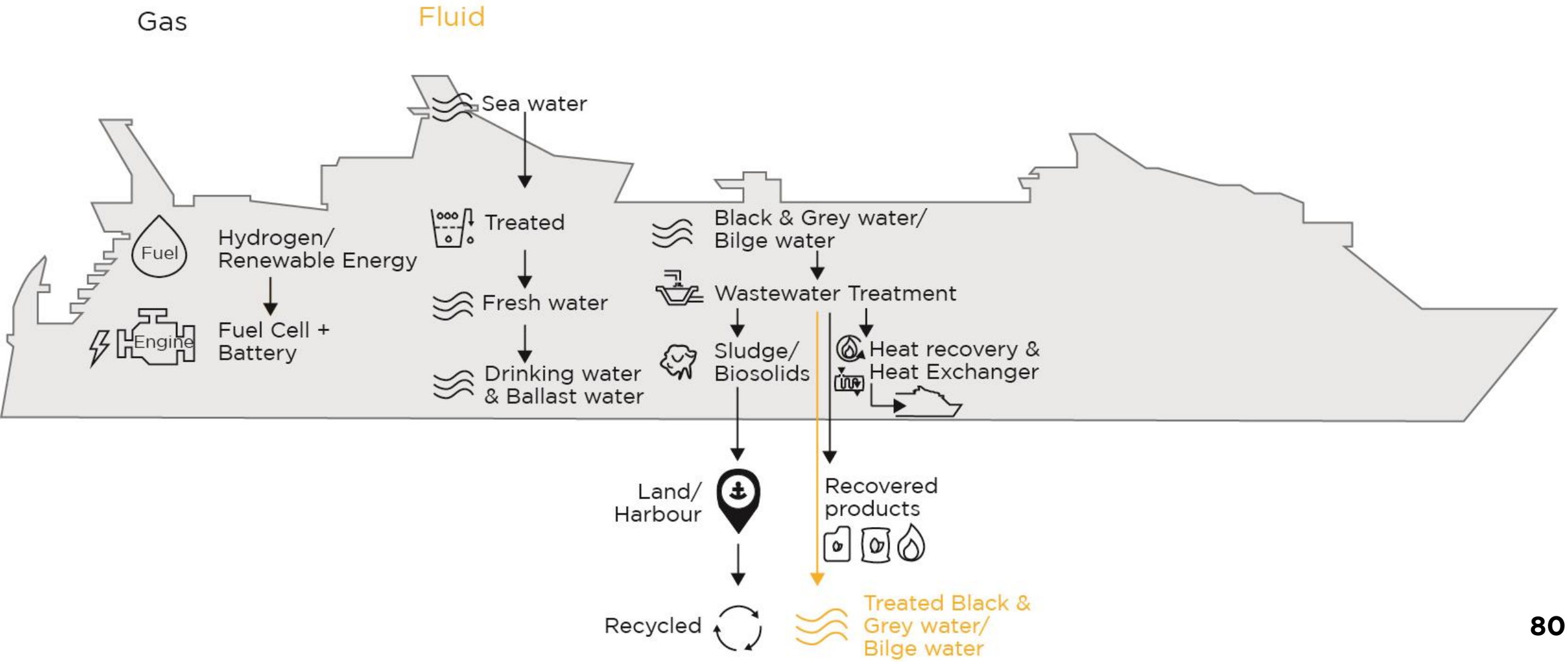
Combination - Retrofit



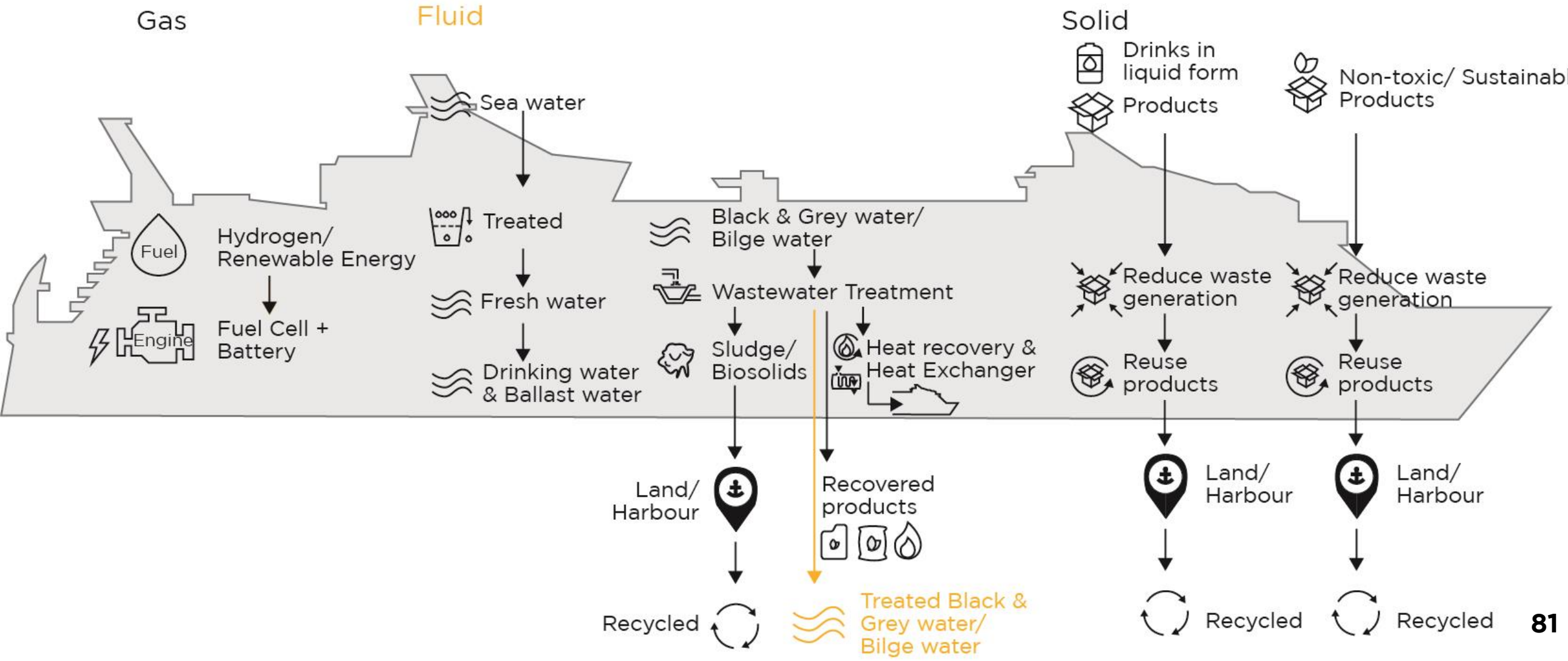
Combination – Newly build

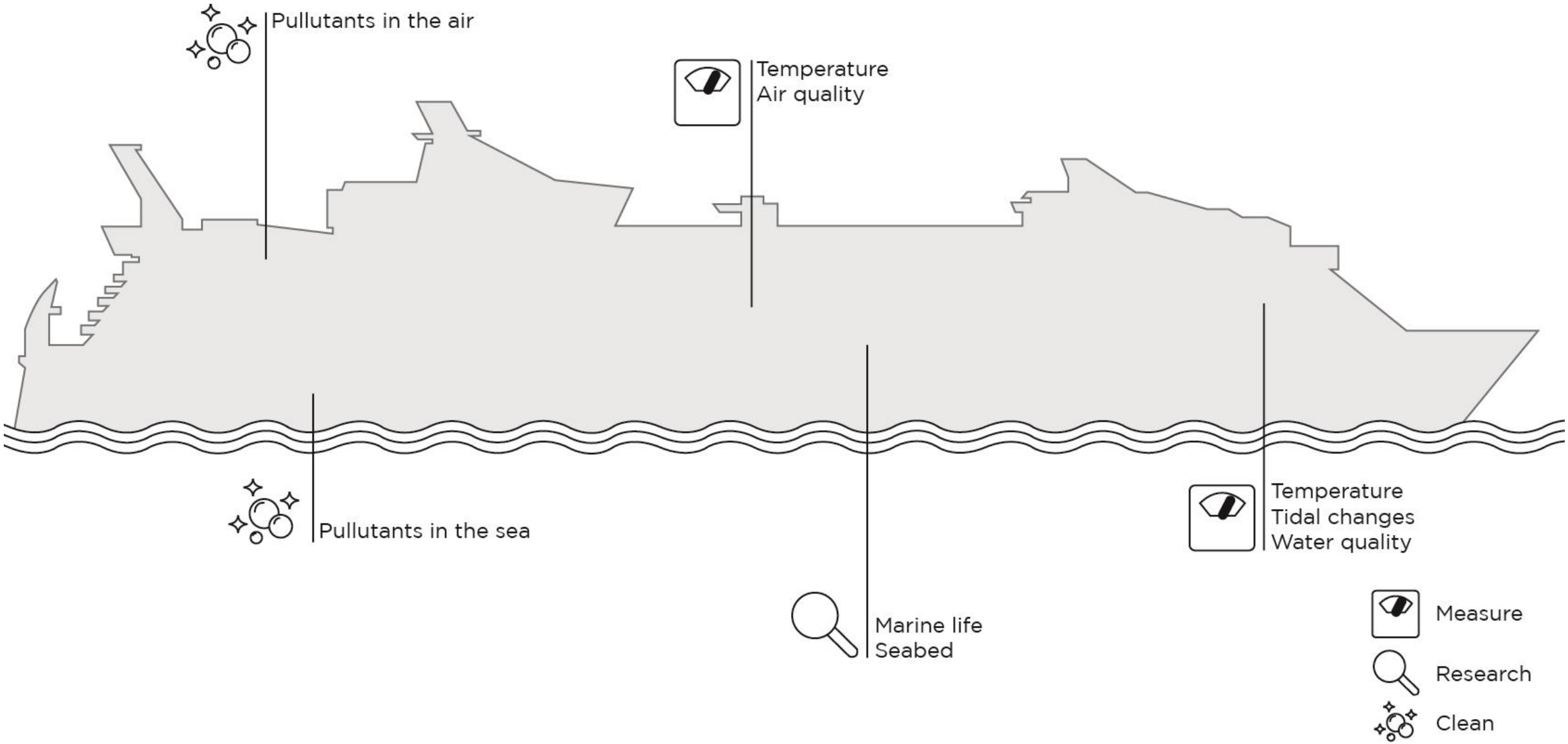


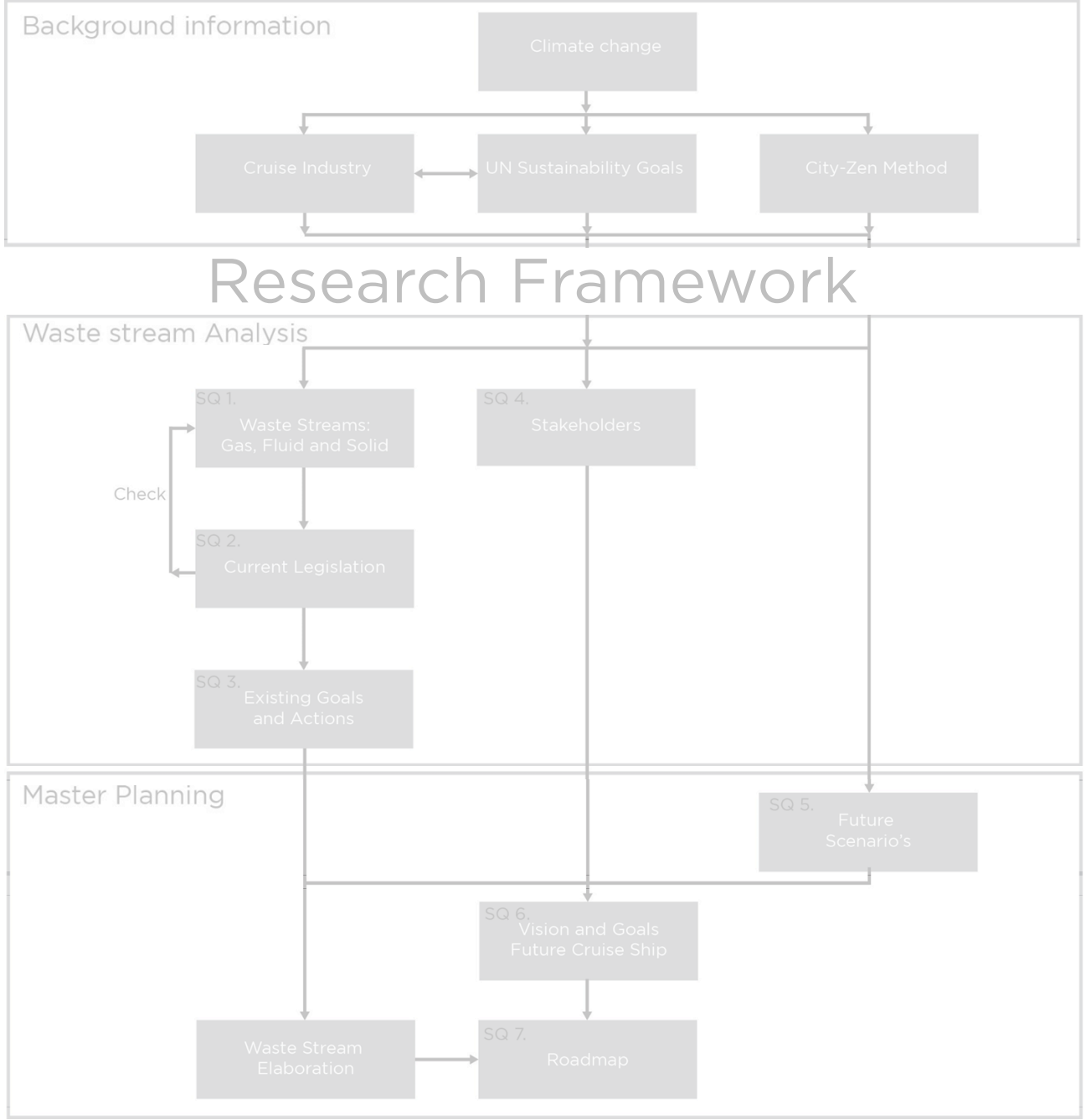
Combination - Newly build



Combination - Newly build

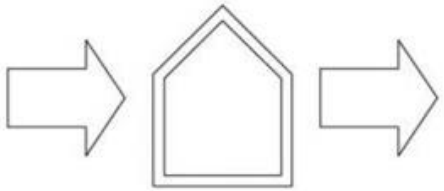



Pullutants in the air
Temperature
Air quality
Pullutants in the sea
Marine life
Seabed
Temperature
Tidal changes
Water quality
Measure
Research
Clean

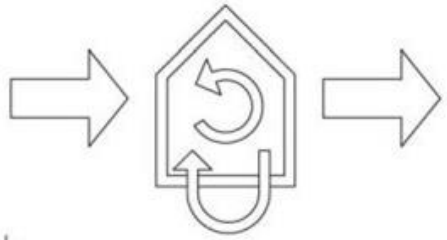


Possible Future Cruise Ship

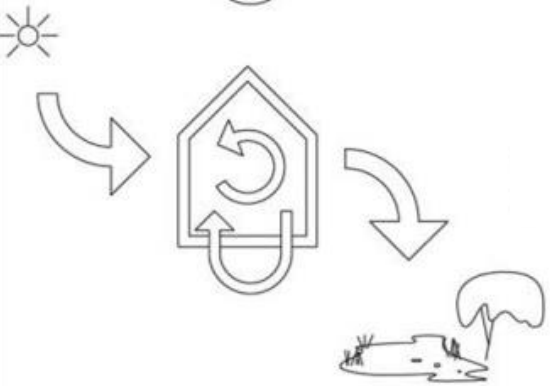
00 Standard Building



01 Reduce consumption

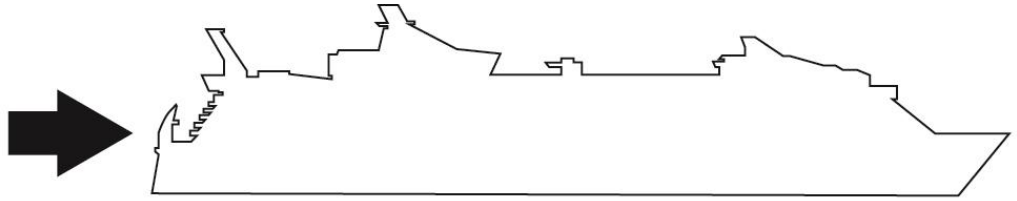


02 Reuse waste energy streams

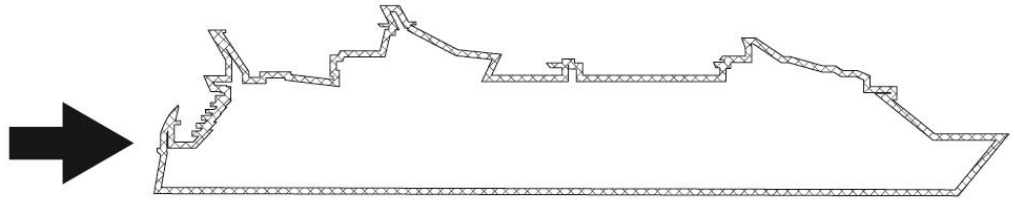


03a Renewable energy production for remaining demand
03b waste = food

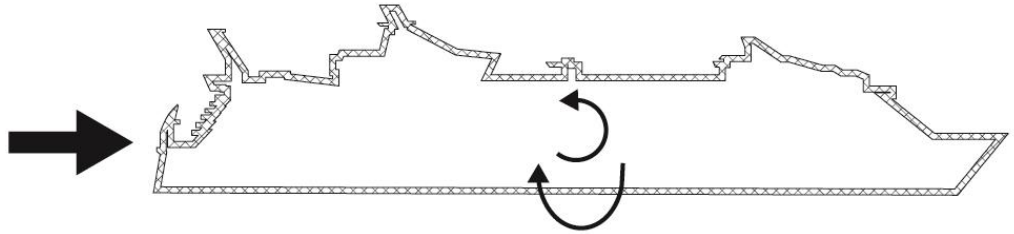
Tillie et al. (2009)



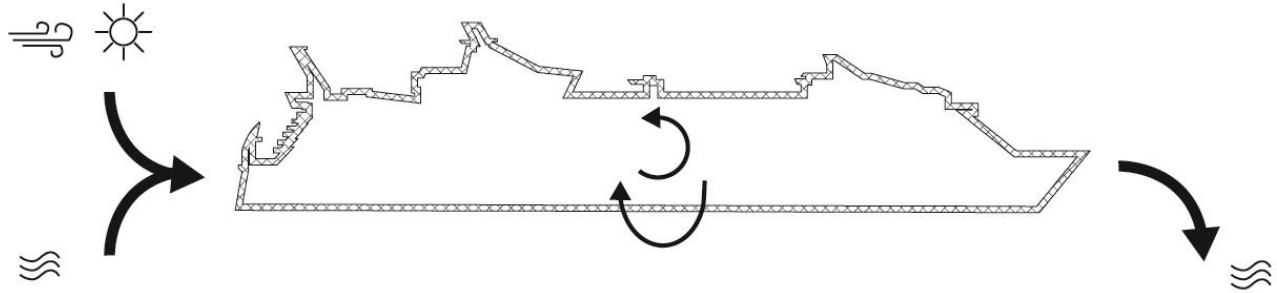
00 Standard Cruise Ship



01 Reduce Consumption
-Passive, Smart & Bioclimatic Design



02 Reuse Waste Energy Streams
-wast heat, waste water, waste material
-In closed or Connected Cycles



03a Renewable Energy Production for Remaining Demand
03b Waste = Food

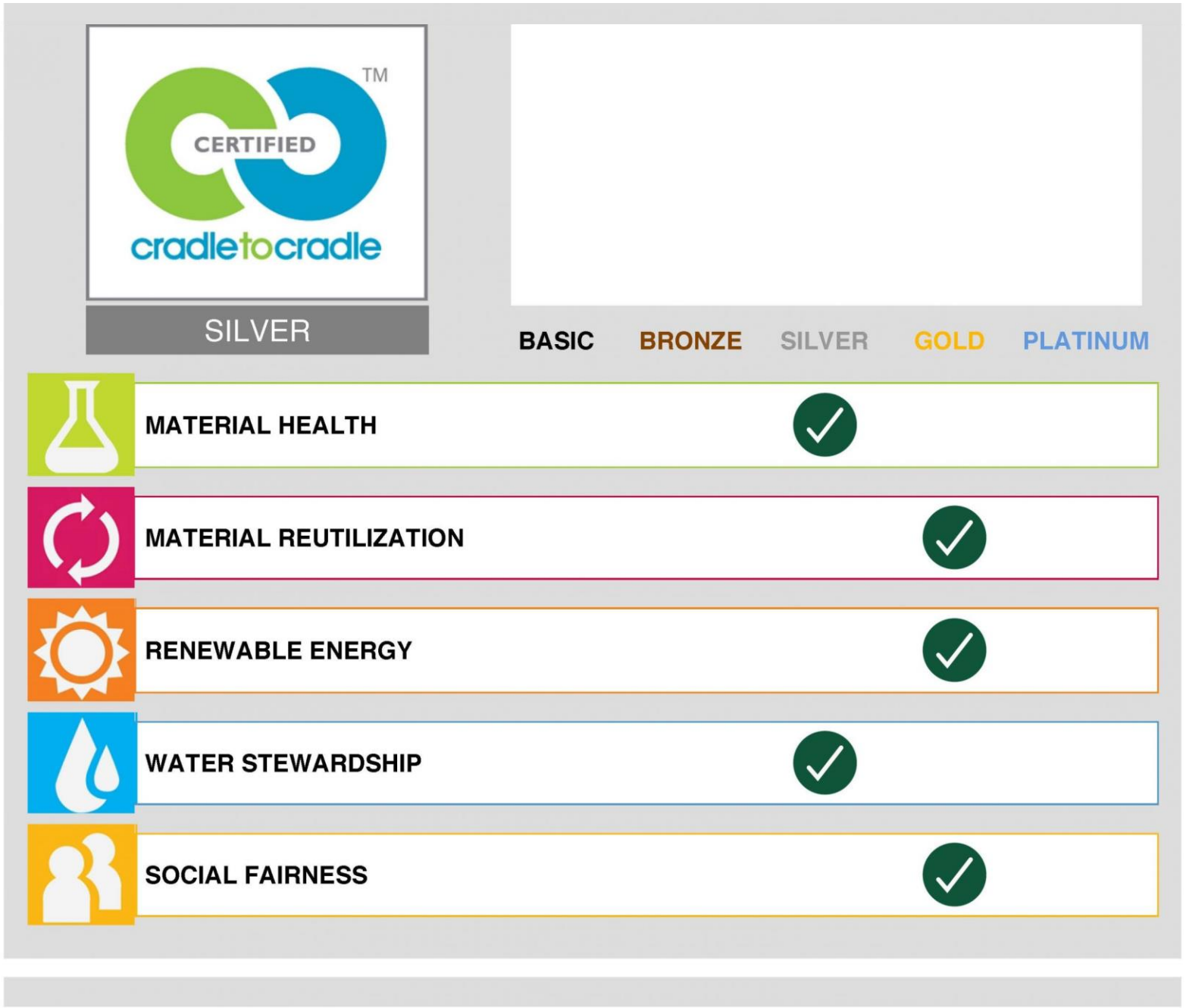
BAMB

BUILDINGS AS MATERIAL BANKS

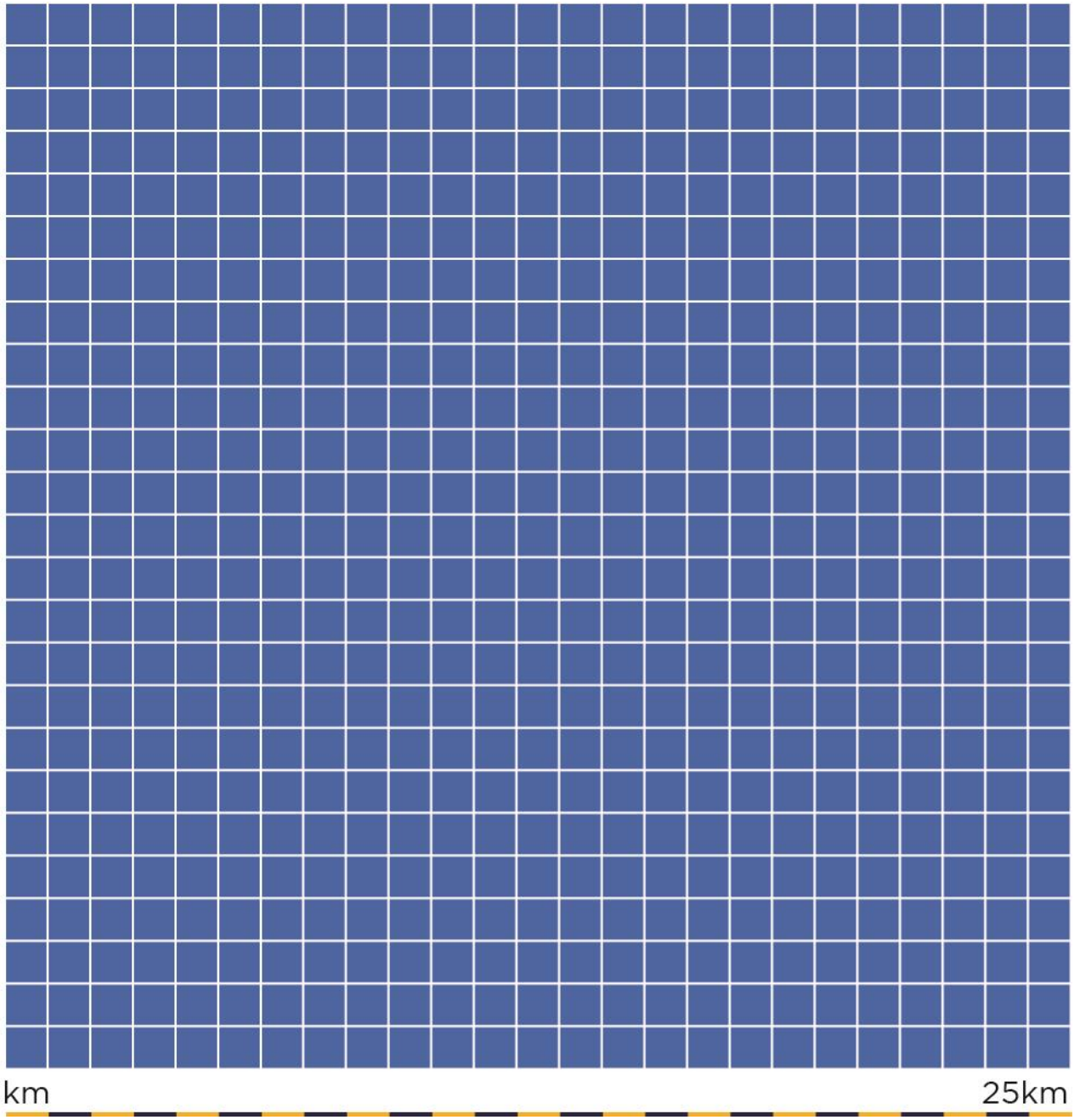
CAMB

CRUISE SHIP AS MATERIAL BANKS

Rau & Oberhuber (2017).



Danskwilton, (n.d.).



Scottish Natural Heritage (n.d.).

3 times

Sagoo, S. (2020)

The sustainable Cruise Ship


NSS 1


NSS 3


NSS 3


NSS 3


NSS 3

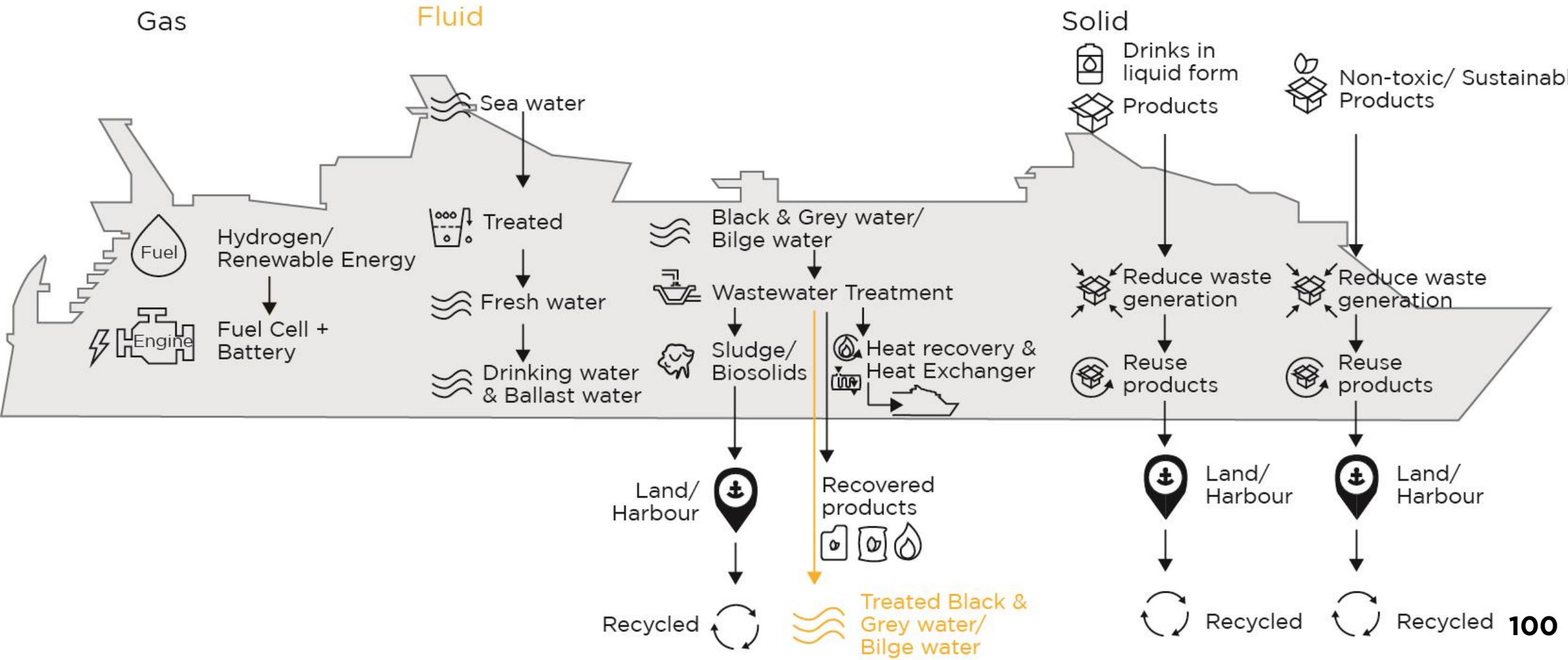

NSS 3

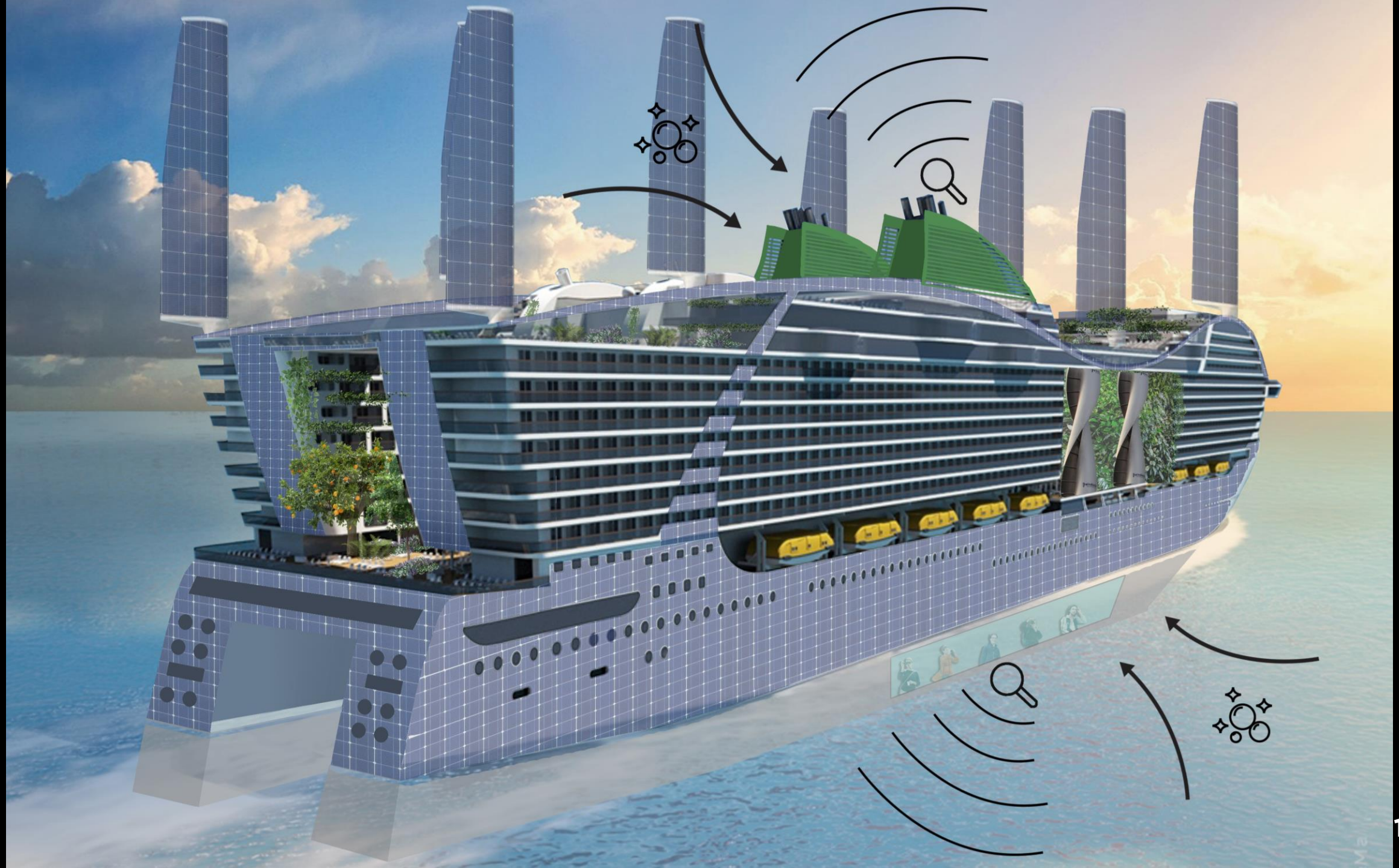

Plants

Cruise Critic (n.d.-a).

Newly build

NSS 2/3





Royal Caribbean International (2019).

Van Gameren, D. (2020)

Warm Climate

Cabins

W | K | E

t: 22-9

Restaurant

W | K | E

t: 17-22

Bar

W | K | E

t: 11-01

Theatre

W | K | E

t: 17-22

Ice Rink

W | K | E

t: 12-22

Casino

W | K | E

t: 10-03

Arcade

W | K | E

t: 10-22

Solarium

W | K | E

t: 9-18

Atrium/ walkways

W | K | E

t: 24/7

Pools

W | K | E

t: 7-23

Gym

W | K | E

t: 6-24

Spa

W | K | E

t: 7-22

Shops

W | K | E

t: 10-23

Play rooms

W | K | E

t: 9-20

Food Storage

W | K | E

t: 24/7

Warm Climate

Cabins

W | K | E
t: 22-9

Restaurant

W | K | E
t: 17-22

Bar

W | K | E
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Theatre

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Casino

W | K | E
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Atrium/ walkways

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W | K | E
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Gym

W | K | E
t: 6-24

Spa

W | K | E
t: 7-22

Shops

W | K | E
t: 10-23

Play rooms

W | K | E
t: 9-20

Food Storage

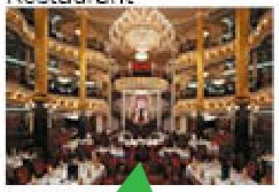
W | K | E
t: 24/7

Warm Climate

NSS 2

Cabins

W | K | E
t: 22-9

Restaurant

W | K | E
t: 17-22

Bar

W | K | E
t: 11-01

Theatre

W | K | E
t: 17-22

Ice Rink

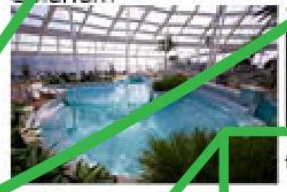
W | K | E
t: 12-22

Casino

W | K | E
t: 10-03

Arcade

W | K | E
t: 10-22

Solarium

W | K | E
t: 9-18

Atrium/ walkways

W | K | E
t: 24/7

Pools

W | K | E
t: 7-23

Gym

W | K | E
t: 6-24

Spa

W | K | E
t: 7-22

Shops

W | K | E
t: 10-23

Play rooms

W | K | E
t: 9-20

Food Storage

W | K | E
t: 24/7

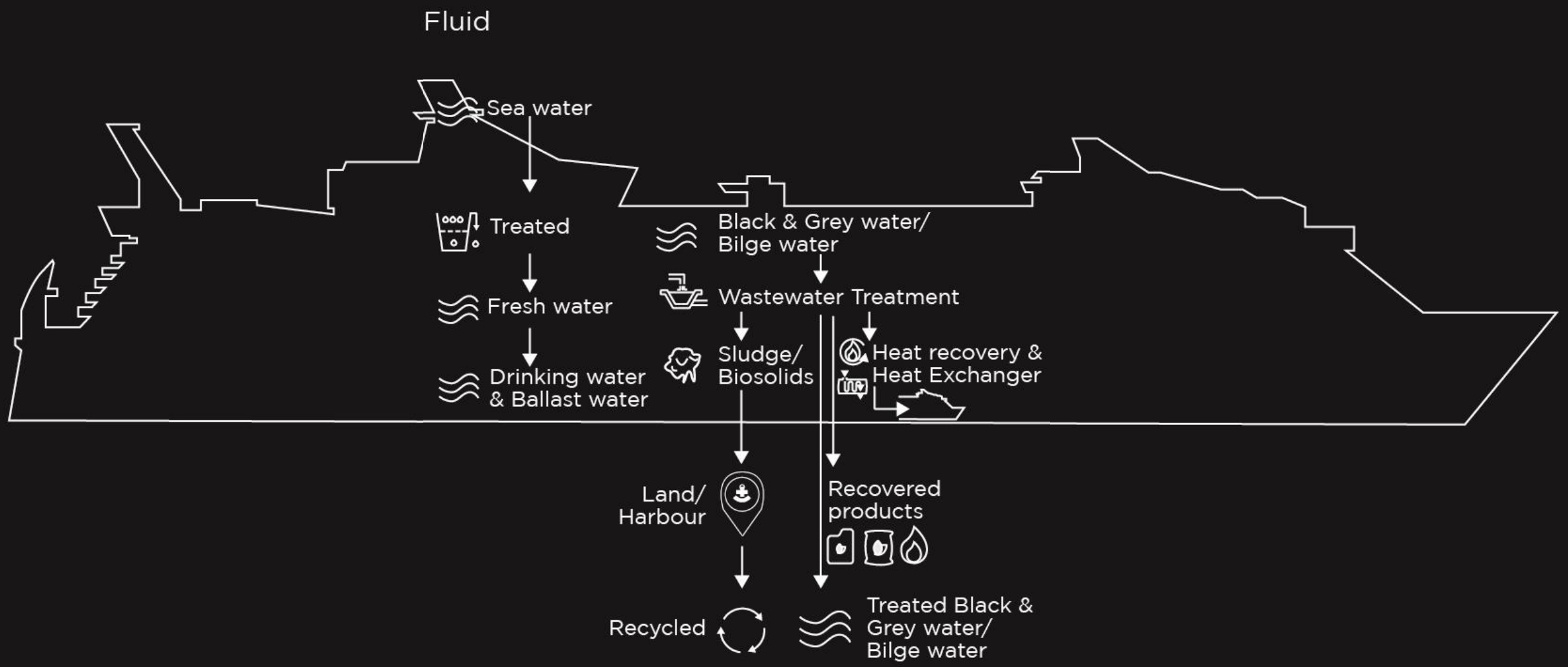

NSS 2

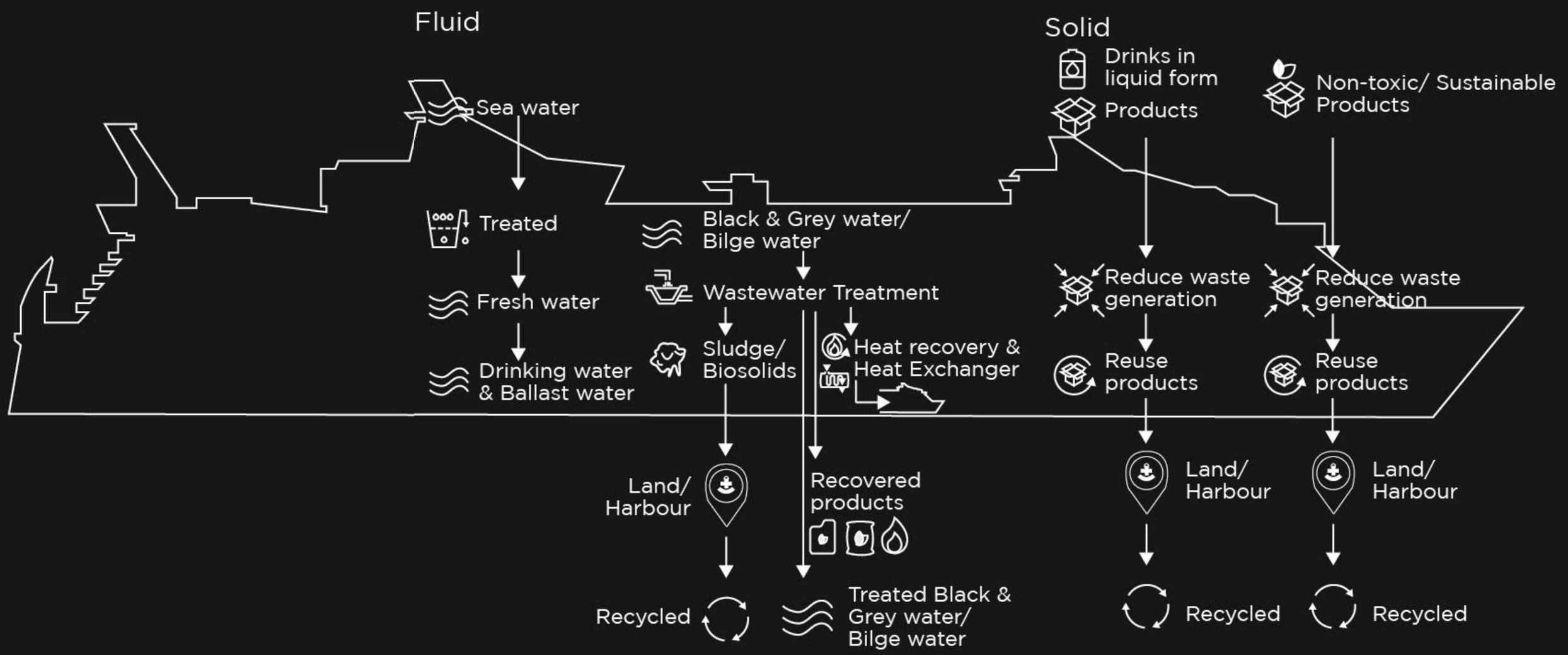

NSS 2

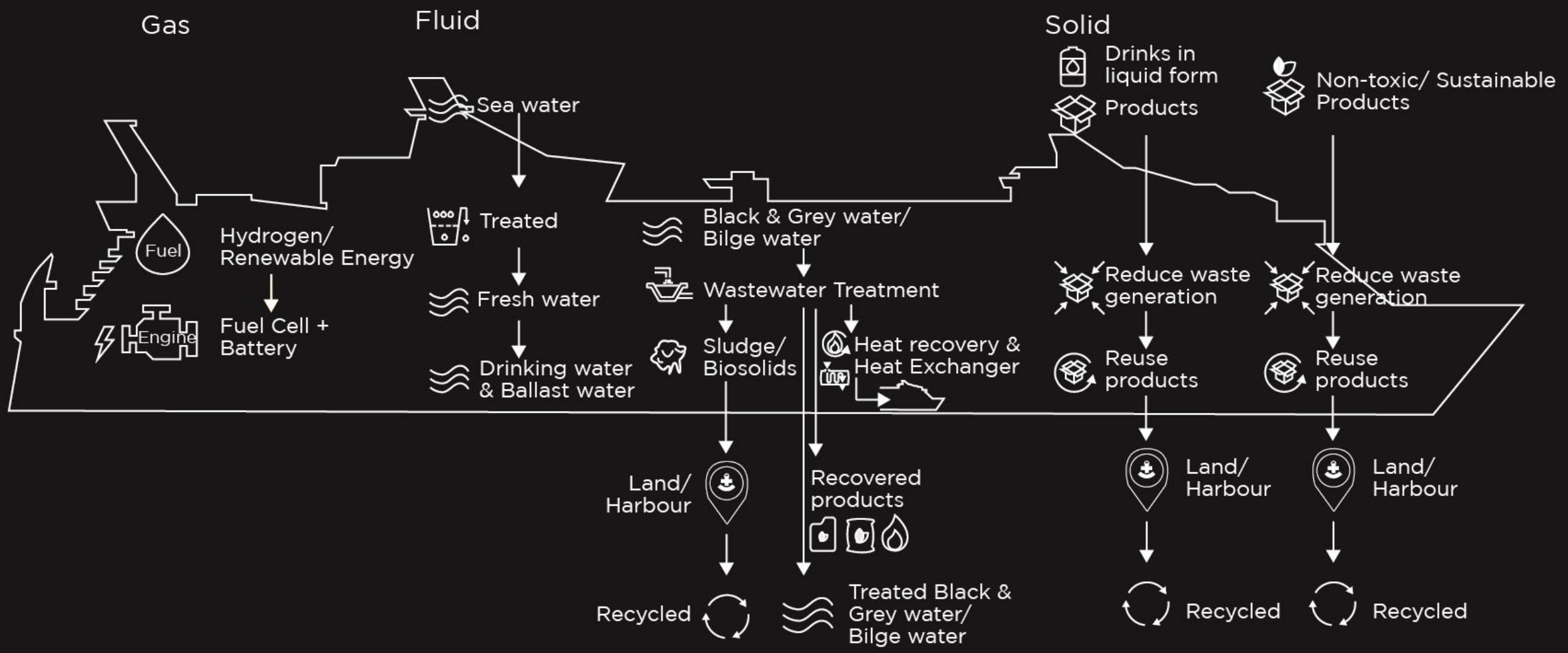
Food

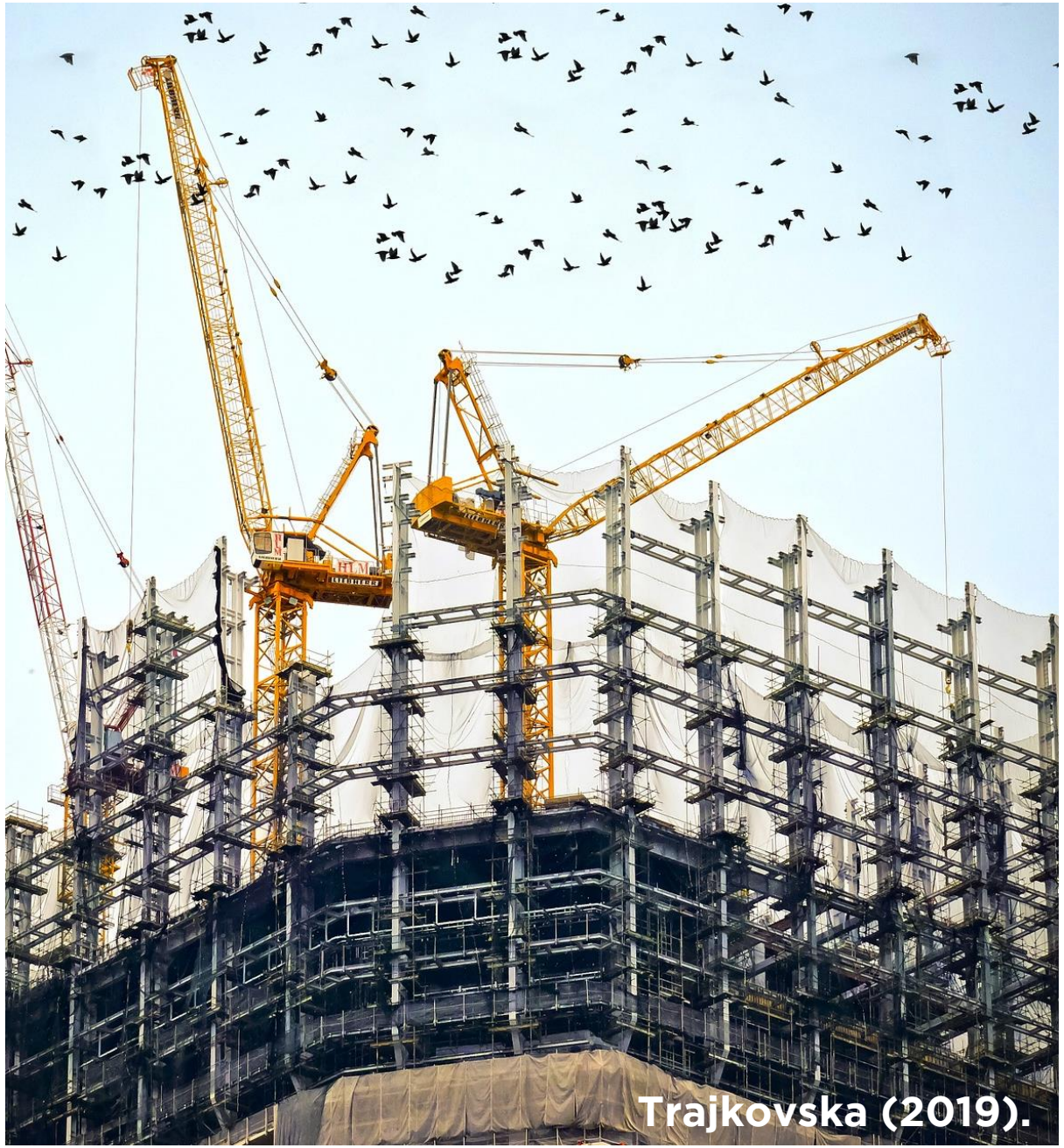
Urbanist (2016).


NSS 3

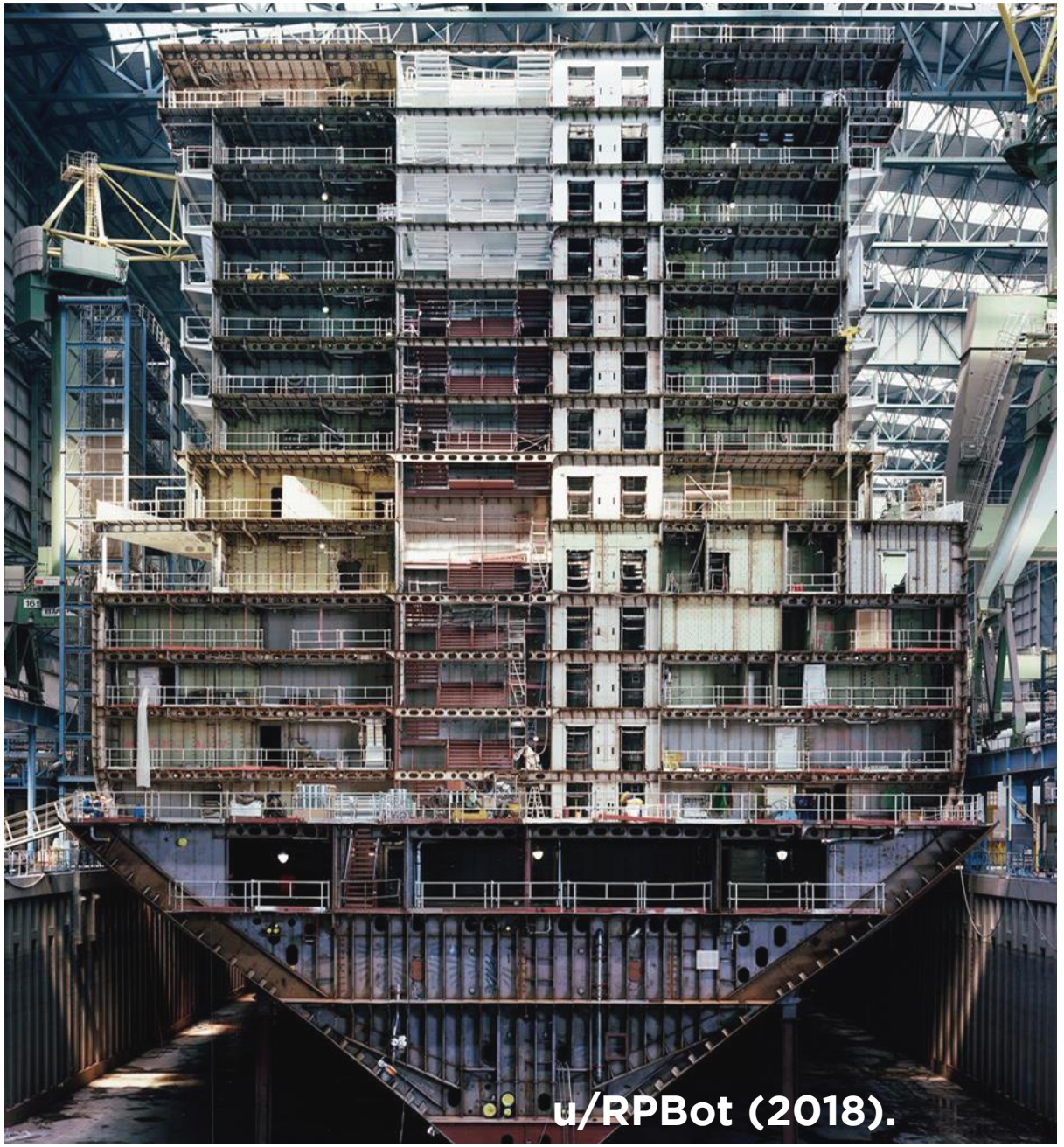

Fluid
Sea water
Treated
Fresh water
Drinking water
& Ballast water
Black & Grey water/
Bilge water
Wastewater Treatment
Sludge/
Biosolids
Heat recovery &
Heat Exchanger
Land/
Harbour
Recovered
products
Recycled
Treated Black &
Grey water/
Bilge water


Fluid
Solid
Sea water
Drinks in liquid form
Products
Non-toxic/ Sustainable Products
Treated
Fresh water
Drinking water & Ballast water
Black & Grey water/ Bilge water
Wastewater Treatment
Sludge/ Biosolids
Heat recovery & Heat Exchanger
Reduce waste generation
Reuse products
Reduce waste generation
Reuse products
Land/ Harbour
Recovered products
Land/ Harbour
Land/ Harbour
Recycled
Treated Black & Grey water/ Bilge water
Recycled
Recycled


Gas
Fluid
Solid
Fuel
Engine
Hydrogen/
Renewable Energy
Fuel Cell +
Battery
Sea water
Treated
Fresh water
Drinking water
& Ballast water
Black & Grey water/
Bilge water
Wastewater Treatment
Sludge/
Biosolids
Heat recovery &
Heat Exchanger
Land/
Harbour
Recycled
Recovered
products
Treated Black &
Grey water/
Bilge water
Drinks in
liquid form
Products
Non-toxic/ Sustainable
Products
Reduce waste
generation
Reuse
products
Land/
Harbour
Recycled
Reduce waste
generation
Reuse
products
Land/
Harbour
Recycled



Trajkovska (2019).



u/RPBot (2018).