Slide#12 solution

i) contant demand

$$\frac{24{,}000\ EJ}{160\ EJ/year} = \mathbf{150\ years}$$

ii) 0.6% annual growth rate

$$24{,}000\ EJ = 160EJ/year\left[\frac{(1+0.006)^n}{0.006}\right]$$

$$(1.006)^n = \frac{24{,}000}{160} \times 0.006$$

$$n \times \log 1.006 = 1.9$$

$$n = \mathbf{107\ years}$$

Sustainability

Today’s lecture

- Sustainability? Being sustainable?
- Sustainability regarding resource consumption
- Sustainable energy sources
- Green engineering and life cycle assessment

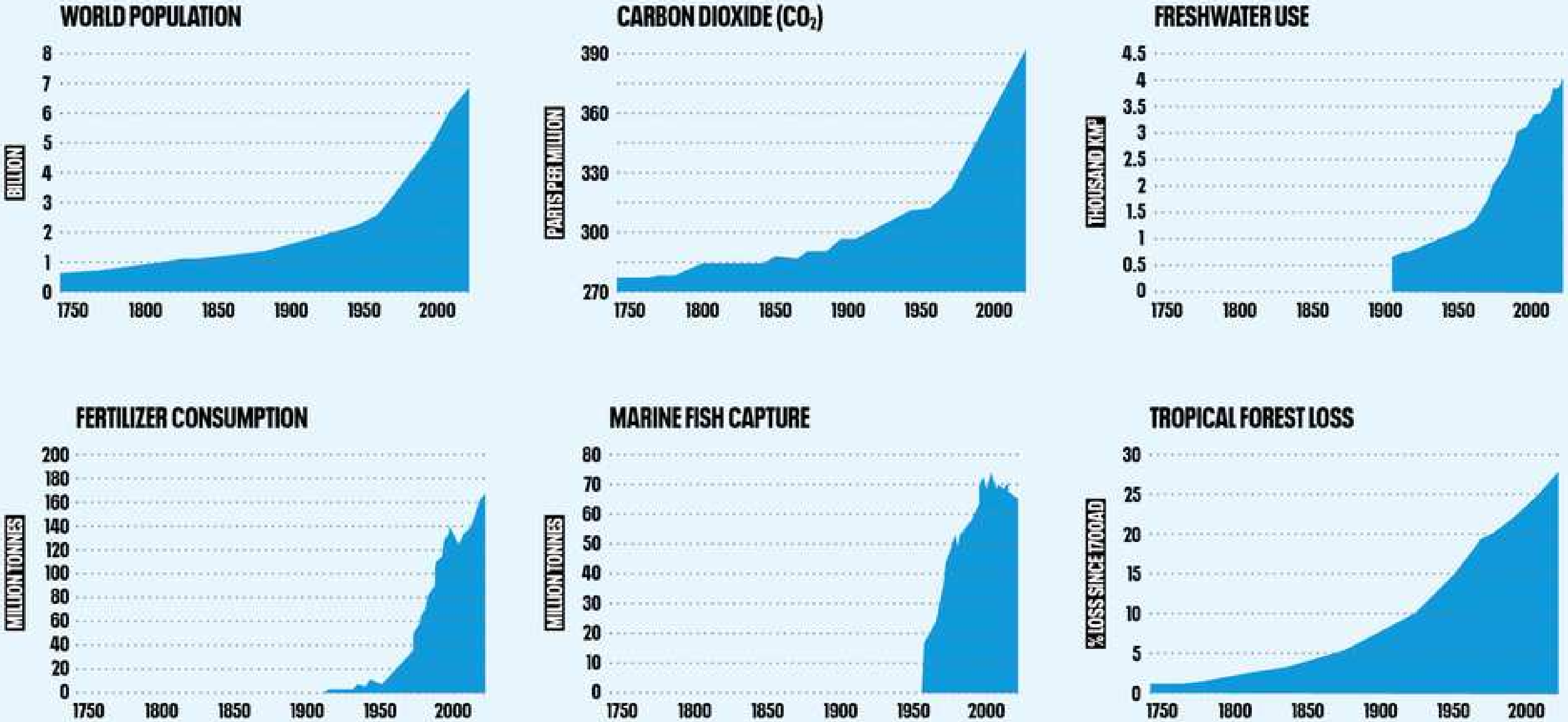
Being “sustainable”: what does it mean?

- Sustainability (in dictionaries)
  – The ability to be maintained at a certain rate or level
  – Harvesting or using a resource so that the resource is not depleted or permanently damaged

- Sustainable development (WCED, 1987)

  Development that meets the needs of the present without compromising the ability of future generations to meet their own needs

HUMAN FOOTPRINT



Source: WWF

UN’s SDG


SUSTAINABLE DEVELOPMENT GOALS
1 NO POVERTY
2 ZERO HUNGER
3 GOOD HEALTH AND WELL-BEING
4 QUALITY EDUCATION
5 GENDER EQUALITY
6 CLEAN WATER AND SANITATION
7 AFFORDABLE AND CLEAN ENERGY
8 DECENT WORK AND ECONOMIC GROWTH
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE
10 REDUCED INEQUALITIES
11 SUSTAINABLE CITIES AND COMMUNITIES
12 RESPONSIBLE CONSUMPTION AND PRODUCTION
13 CLIMATE ACTION
14 LIFE BELOW WATER
15 LIFE ON LAND
16 PEACE, JUSTICE AND STRONG INSTITUTIONS
17 PARTNERSHIPS FOR THE GOALS
SUSTAINABLE DEVELOPMENT GOALS

http://sdgs.un.org/goals

지속가능발전포털

검색어를 입력하세요.

지속가능발전

지속가능발전 | 국가지속가능발전목표 K-SDGs | 정보마당 | 국민참여마당 | 지속가능발전위원회

K-SDGs 소개 | 배경과 의의 | 세부목표와 지표 | 심볼 다운로드

국가지속가능발전목표(K-SDGs)

국가 지속가능발전목표 119개 세부목표 및 236개 지표 [원문보기]

http://ncsd.go.kr/

목표 1. 빈곤층 감소와 사회안전망 강화

세부목표 1-1. "남녀노소, 장애여부 등과 관계 없이 빈곤인구 비율을 OECD 평균 이하 수준으로 줄인다."

지표 및 목표

	지표명	현 수치	목표
K-SDGs 세부목표 1-1	(1) 중위 가처분소득 50% 기준 상대빈곤율	- 2018: 16.7%	- 2030: 14.3% - 2040: 11.8%
	(2) 복지 급여(소득보장) 예산 및 GDP 대비 비율	- 2018: 0.97%	- 2030: 1.0% 이상 - 2040: 1.5% 이상

정책 과제

① 공공부조제도 역할 강화
② 노후소득보장체계 확충

세부목표 1-2. "사회보장제도의 사각지대를 최소화하고, 빈곤층과 취약계층에 대한 실질적 보장을 달성한다."

지표 및 목표

	지표명	현 수치	목표
K-SDGs 세부목표 1-2	(1) 의료비 가계직접 본인부담률	- 2018: 36.2%	- 2030: 30.0% - 2040: 25.0%
	(2) 고용보험 가입률	- 2019: 90.3%	- 2030: 90.0% - 2040: 99.0%
	(3) 국민연금 보험료 납부율	- 2018: 78.6%	- 2030: 82.5% - 2040: 84.2%

정책 과제

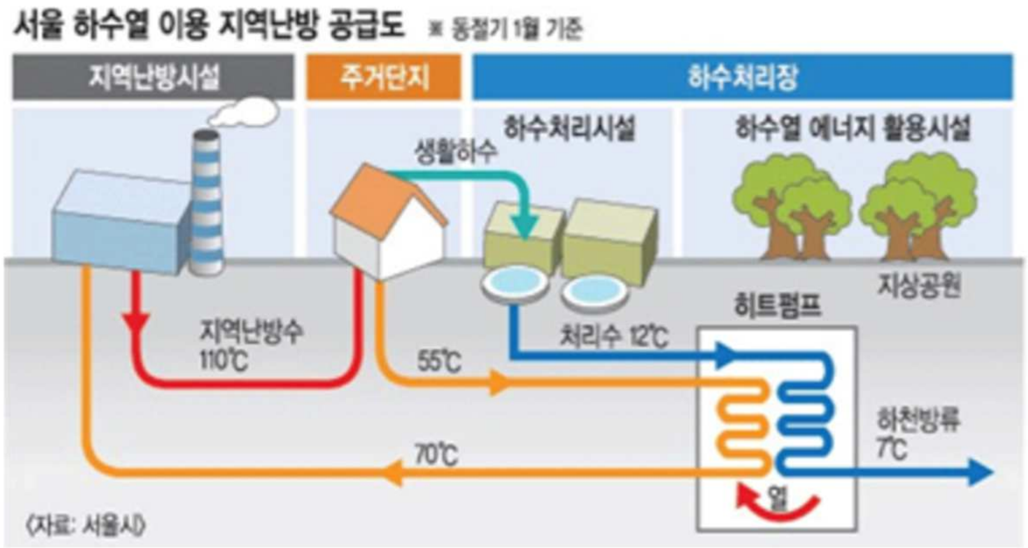
① 국민의료비 부담 경감
② 고용보험 및 산재보험 적용대상 확대를 통한 사각지대 해소
③ 취약계층을 위한 노후보장 강화

Resources: renewable vs. nonrenewable

- Renewable resources
  - Resources that can be replaced within a few human generations
  - timber, surface water, solar energy, wind energy

- Nonrenewable resources
  - Resources that are replaceable only in geologic time scales
  - fossil fuels (coal, petroleum, natural gas), metal ores

Are these renewable?
Do they help improving the global sustainability?



Fossil fuel

Typical net heating values

Material	**Net heating value ($MJ\ kg^{-1}$)**
Charcoal	26.3
Coal, anthracite	25.8
Coal, bituminous	28.5
Fuel oil, no. 2 (home heating)	45.5
Fuel oil, no. 6 (bunker C)	42.5
Gasoline (regular, 84 octane)	48.1
Natural gas	53.0
Wood	13.3-22.3

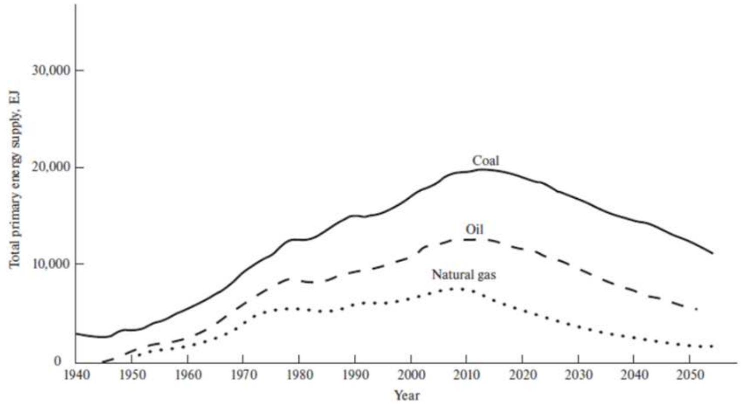
MJ: megajoule, 10^6 J

World commercial energy reserves of fossil fuels

Fuel	**Energy reserves (EJ)**
Coal	24,000
Oil	12,700
Natural gas	7,500

EJ: exajoule, 10^{18} J

World fossil fuel supply (record+forecast)



The length of time the current reserves will last

- Assuming constant demand over time

$$T_s = \frac{F}{A}$$

T_s = time until exhaustion (yr)
F = energy reserve (EJ)
A = annual demand (EJ yr^{-1})

- Assuming geometric growth in demand:
  solve for n from the following equation

$$F = A\left[\frac{(1+i)^n - 1}{i}\right]$$

n = number of years until exhaustion
i = annual growth rate (in fraction)

The length of time the current reserves will last

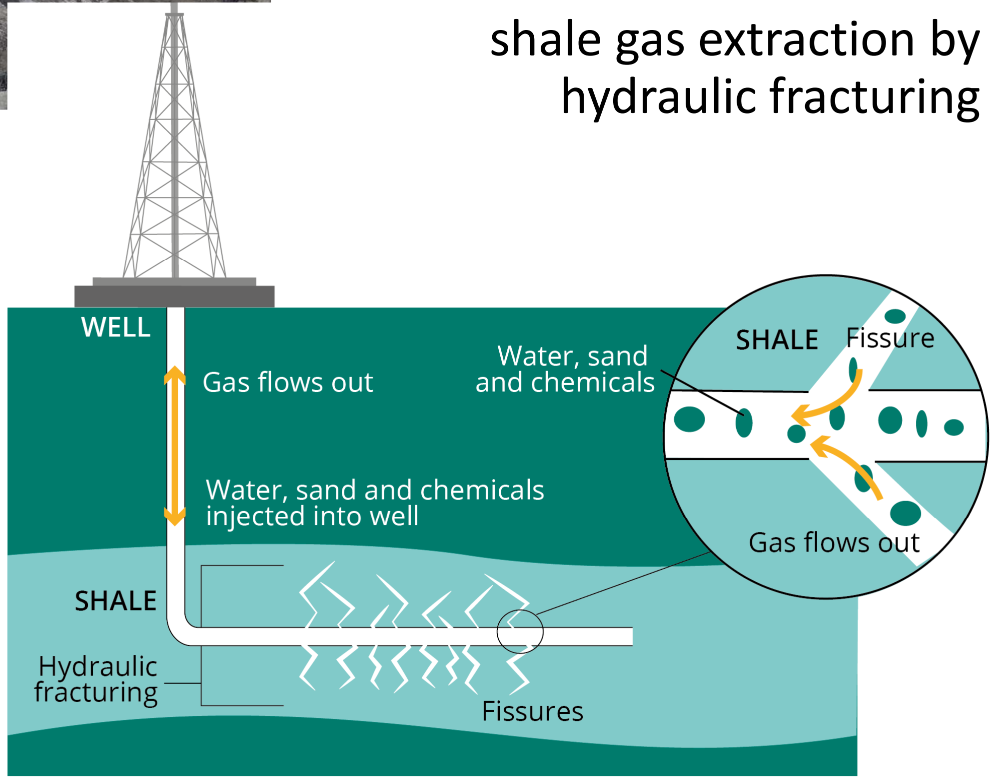
Q: In 2015, the world consumption of coal for energy was 160 EJ. Assuming the demand remains constant, how long will world reserves last? The estimate of the average world consumption of coal-based energy ranged from a 0.6% increase to a 1.8% decrease in 2015. Using the 0.6% increase, estimate how long the world's coal reserves will last.

More fossil fuel reserves

- Tar sands (oil sands) & shale gas
  - Not included in slide#10 data
  - Discovered (or mining became feasible) recently
  - Consumes a huge amount of water / generates highly polluted water
- **Tar sands**
  - Sands laden with petroleum
  - Estimated reserves: 3.7×10^{11} m^3
  - Amount recoverable with current technology: 2.8×10^{10} m^3
- **Shale gas**
  - Estimated reserves: 4,000 EJ in 2010, being updated with rapidly growing quantity
  - Natural gas in shale formations
  - Mined by hydraulic fracturing

tar sands

shale gas extraction by
hydraulic fracturing



Renewable energy sources (1)

- **Hydropower**
  - Potential E of water $\longrightarrow$ Kinetic E of water $\xrightarrow{\textit{turbine}}$ Electricity
  - Power available $= g(\Delta Z)\dfrac{dM}{dt} = g(\Delta Z)\rho Q$

g = acceleration due to gravity (=9.81 $m \cdot s^{-1}$)
ΔZ = difference in water elevation between the water surface at the top of the dam and the turbine (m)
dM/dt = mass flow rate of water ($kg \cdot s^{-1}$)
ρ = water density ($kg \cdot m^{-3}$)
Q = water flow rate ($m^3 \cdot s^{-1}$)

- **Solar energy**
  - Photovoltaic systems: good for distributed generation & supply
- **Wind, geothermal, wave, tidal, …**


전력 판매
(SMP)
태양광 발전
인증서 판매
(REC)
태양광발전
사업 구조
“재생에너지 발전비중 7%→20%”
자가용·농촌 태양광 장려
정부가 2030년까지 재생에너지 발전량 비중을
20%로 늘리기 위해
총 110조원을 들여 48.7GW(기가와트)
규모의 재생에너지 설비를 확충하기로 함
한국전력
SMP(System Marginal Price)
생산된 전력을
한국전력에 판매하는
가격(원/kWh)
발전사업자 (21개사)
REC (Renewable Energy Certificate)
신재생에너지로 전기를
생산, 공급하였음을
증명하는 인증서(원/kWh)

Renewable energy sources (2)

- **Biofuels from biomass**
  - Combustion of biomass
  - Recovering fuel from biomass: bioethanol, biodiesel, biobutanol, …

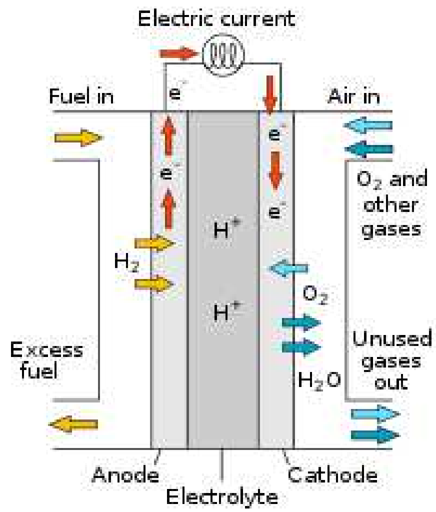
- **Bioethanol**
  - feedstock (ex: corn) $\xrightarrow[\textit{(by acid or enzyme)}]{\textit{hydrolysis}}$ glucose $\xrightarrow[\textit{(by yeast)}]{\textit{fermentation}}$ ethanol
  - Blended with gasoline

- **Biodiesel**
  - Use soybean oil (ex: canola oil) as feedstock, produce alkyl esters using f…?, blended with diesel

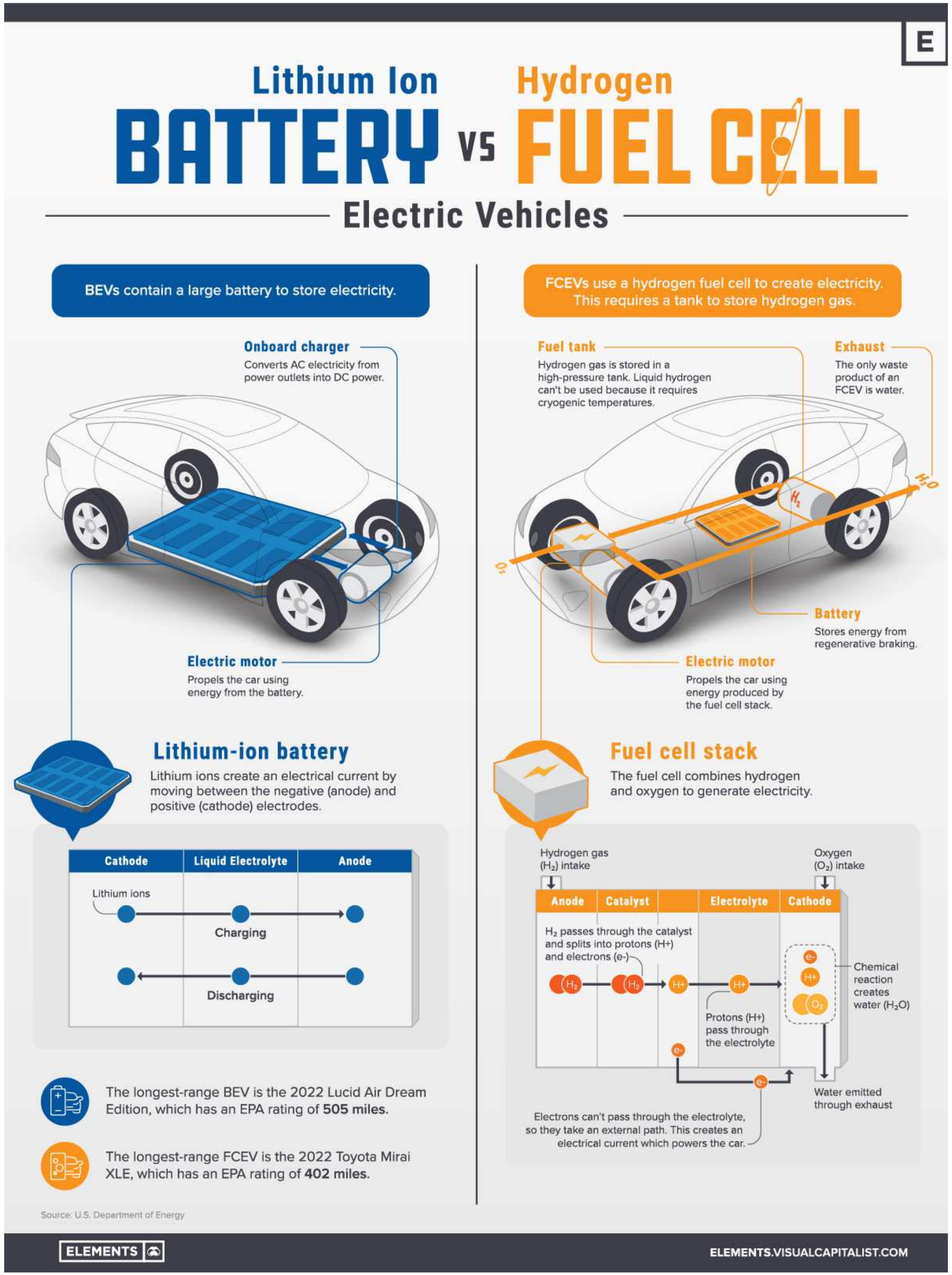
- **Biobutanol, biomethane**

Hydrogen

- Oxidized in a fuel cell to generate electricity
- No pollutant generation in fuel cells
- To be a renewable energy H_2 should be generated from renewable sources (ex: water splitting in photovoltaic cells)
- Challenges
  - High cost, longevity of the fuel cell, safety concerns, transport & storage problem of H_2, poor infrastructure



<fuel cell>


E
Lithium Ion
BATTERY
VS
Hydrogen
FUEL CELL
Electric Vehicles
BEVs contain a large battery to store electricity.
FCEVs use a hydrogen fuel cell to create electricity. This requires a tank to store hydrogen gas.
Onboard charger
Converts AC electricity from power outlets into DC power.
Electric motor
Propels the car using energy from the battery.
Fuel tank
Hydrogen gas is stored in a high-pressure tank. Liquid hydrogen can't be used because it requires cryogenic temperatures.
Exhaust
The only waste product of an FCEV is water.
Battery
Stores energy from regenerative braking.
Electric motor
Propels the car using energy produced by the fuel cell stack.
Lithium-ion battery
Lithium ions create an electrical current by moving between the negative (anode) and positive (cathode) electrodes.
Cathode
Liquid Electrolyte
Anode
Lithium ions
Charging
Discharging
Fuel cell stack
The fuel cell combines hydrogen and oxygen to generate electricity.
Hydrogen gas (H_2) intake
Oxygen (O_2) intake
Anode
Catalyst
Electrolyte
Cathode
H_2 passes through the catalyst and splits into protons (H+) and electrons (e-)
Protons (H+) pass through the electrolyte
Chemical reaction creates water (H_2O)
Water emitted through exhaust
Electrons can't pass through the electrolyte, so they take an external path. This creates an electrical current which powers the car.
The longest-range BEV is the 2022 Lucid Air Dream Edition, which has an EPA rating of 505 miles.
The longest-range FCEV is the 2022 Toyota Mirai XLE, which has an EPA rating of 402 miles.
Source: U.S. Department of Energy
ELEMENTS
ELEMENTS.VISUALCAPITALIST.COM

Green engineering

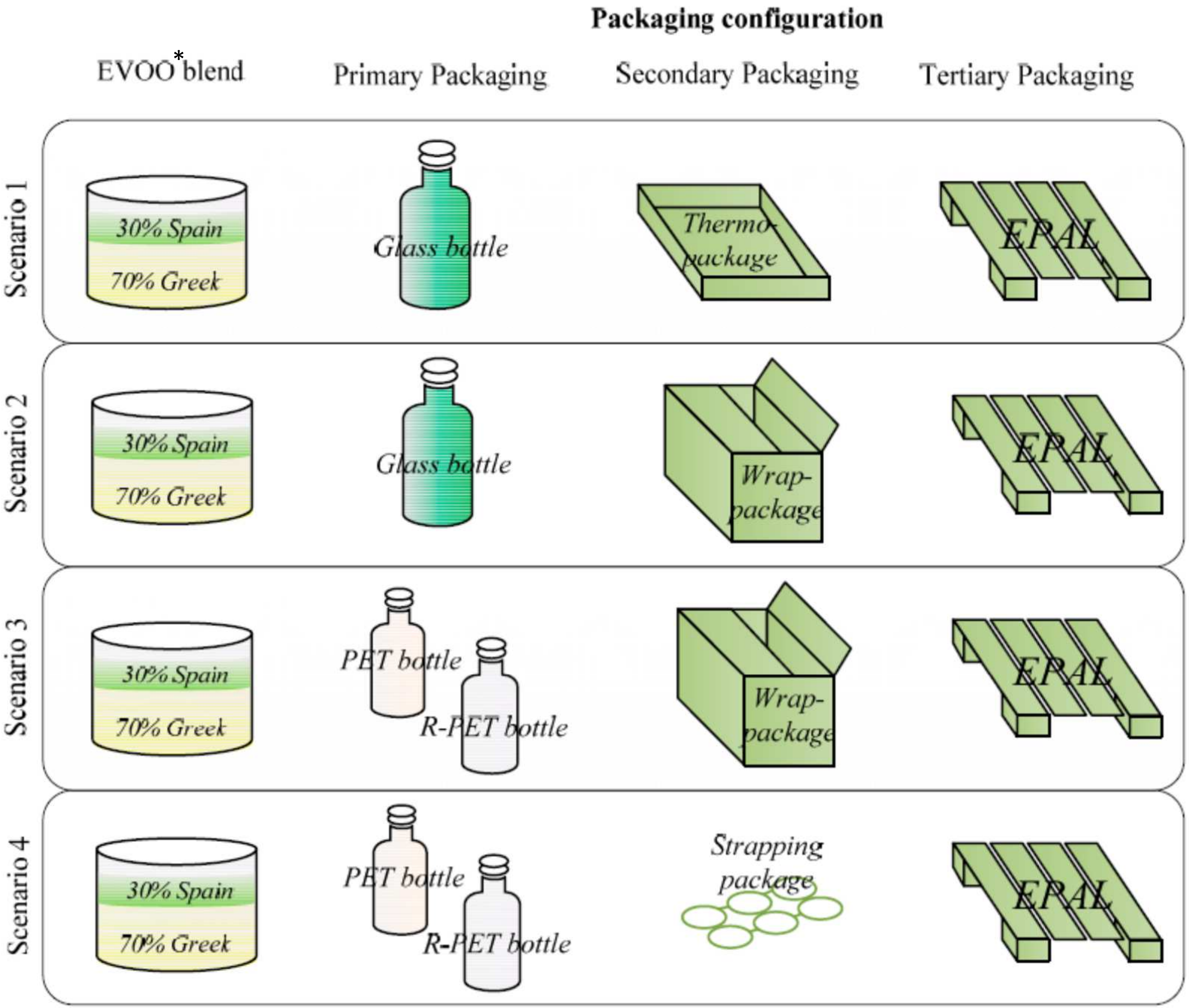
- Design, commercialization, and use of processes and products that are feasible and economical while
- **Reducing the generation of pollution at the source**
- **Minimizing risk to human health and the environment**

- Need to consider the whole life cycle (from cradle to grave) of products
  - Mining/collecting resources, production, use, waste management including disposal, and transportation involved
  - Generation of pollution and risk for each step
  - Potential ways to reduce the pollution and risk

Life cycle assessment

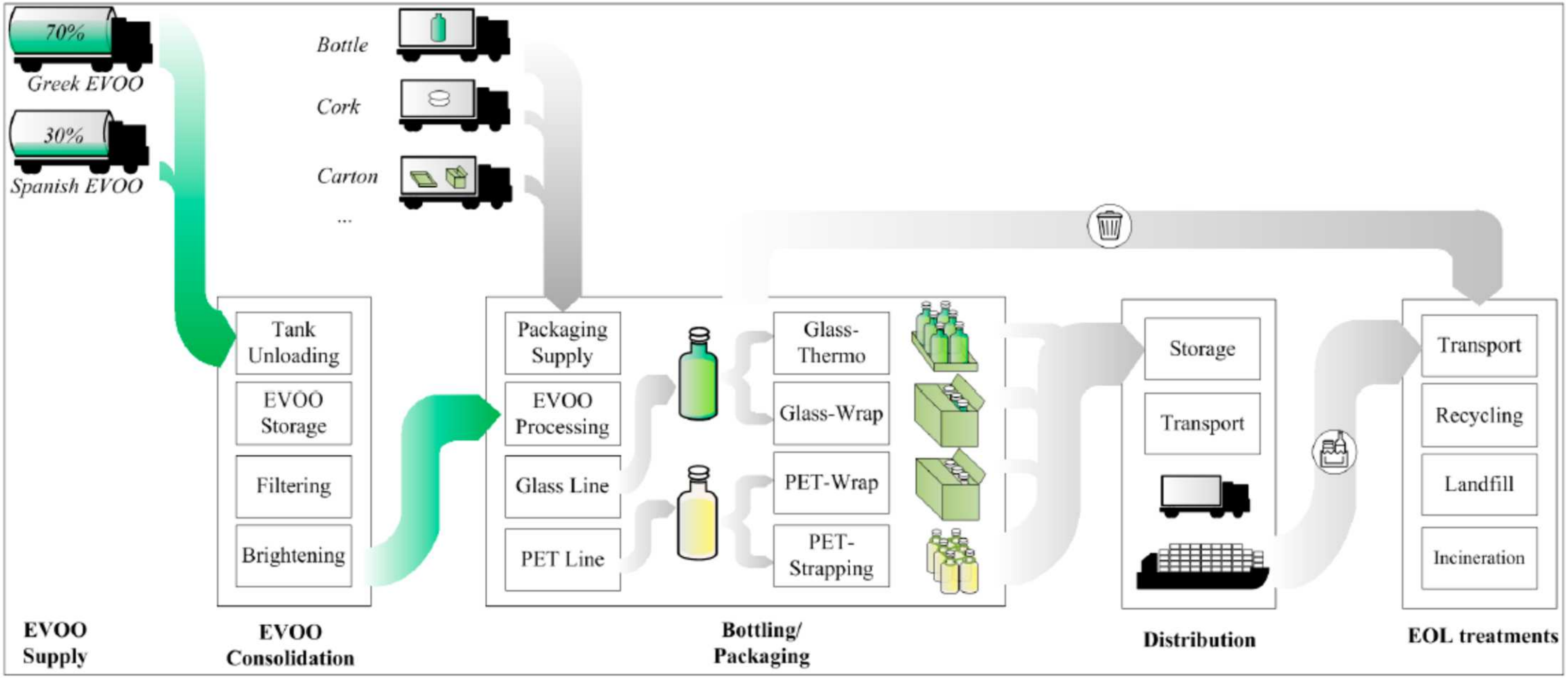
- A technique to assess the assess the environmental aspects and potential impacts associated with a product, process, or service, by
  - compiling an inventory of relevant energy and material inputs and environmental releases;
  - evaluating the potential environmental impacts associated with identified inputs and releases;
  - interpreting the results to help you make a more informed decision.

Life cycle assessment example: glass vs. PET bottle



*EVOO:
extra virgin olive oil

Defining the system boundary

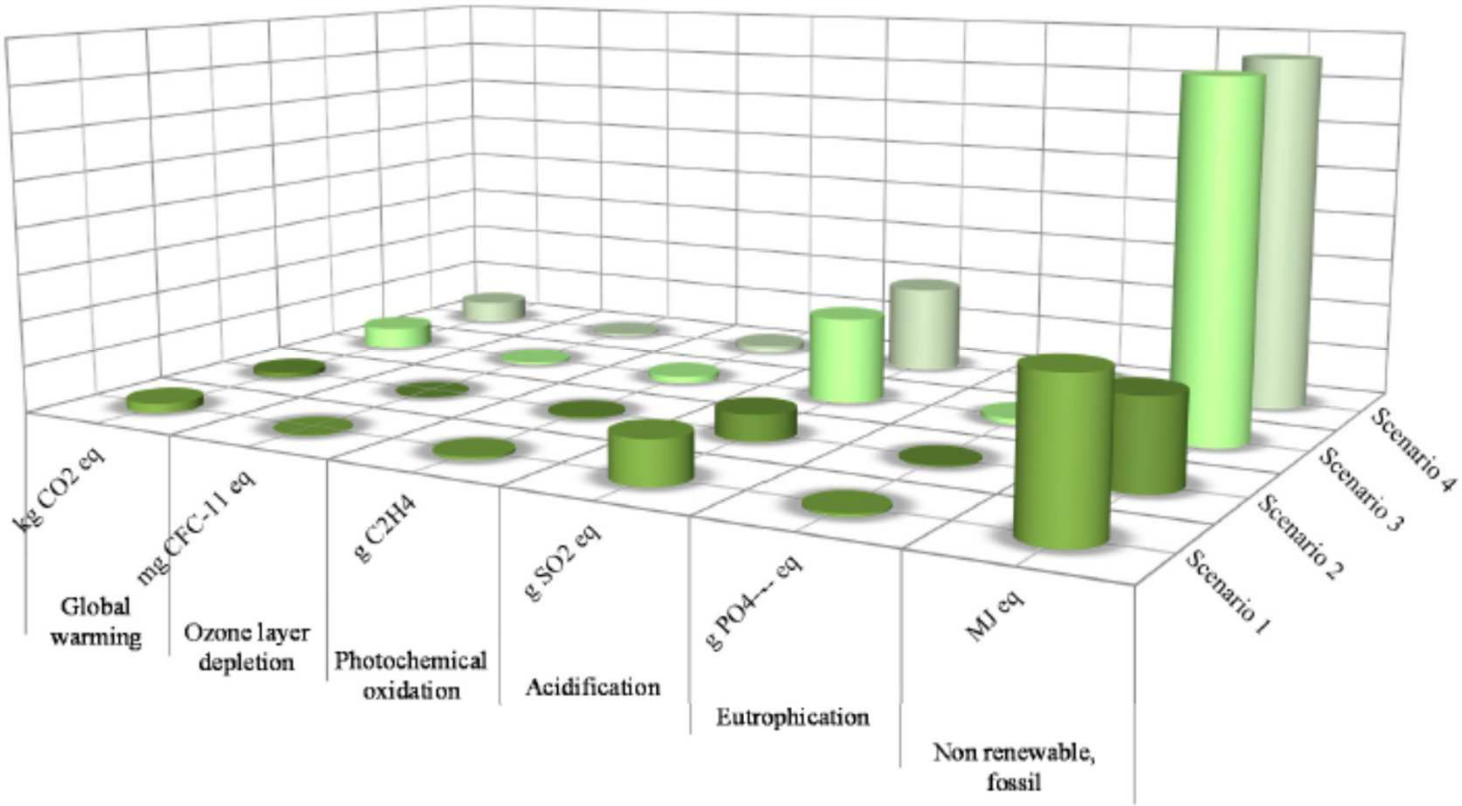


Life cycle inventory

Table 1. Life cycle inventory: primary and secondary data source per each function unit (FU) scenario. EOL, end-of-life; PP, polypropylene; tkm, ton·km; ARPA, Regional agency for prevention and environment (Emilia-Romagna).

Process	Processes/Materials	Unit	Amount	Data Sources	Scenarios (FUs)			
					Scenario 1	Scenario 2	Scenario 3	Scenario 4
EVOO Supply	Transport	tkm	1.43	Ecoinvent database	•	•	•	•
Consolidation	Energy	kWh/FU	0.006	On-field monitoring	•	•	•	•
Brightening	Energy	kWh/FU	0.00719	On-field monitoring	•	•	•	•
Filtering	Cellulose fossil flour	g./FU	2	On-field monitoring, Interview	•	•	•	•
	Cellulose assembled filter	g./FU	0.0050325	On-field monitoring, Interview	•	•	•	•
PET bottling line	PET bottle	g./FU	36	Ecoinvent database			•	•
	PET cap	g./FU	3.8	Ecoinvent database			•	•
	PET sleever	g./FU	5	On-field monitoring			•	•
	Wood pallet	g./FU	25.8	Ecoinvent database			•	•
	PE film	g./FU	0.72	Ecoinvent database			•	•
	Energy	kWh/FU	0.0338	On-field monitoring			•	•
PET-wrap line	Cardboard wrap	g./FU	20.1	On-field monitoring			•	
PET-strapping line	PP stripe	g./FU	0.75	Ecoinvent database				•
Glass bottling line	Glass bottle	g./FU	460	Ecoinvent database	•	•		
	Aluminum cap	g./FU	3	Ecoinvent database	•	•		
	PE pourer	g./FU	2	On-field monitoring	•	•		
	Labels	g./FU	4	On-field monitoring	•	•		
	Wood pallet	g./FU	41.3	Ecoinvent database	•	•		
	PE film	g./FU	0.65	Ecoinvent database	•	•		
	Energy	kWh/FU	0.0107	On-field monitoring	•	•		
Glass-wrap line	Cardboard wrap	g./FU	20.4	On-field monitoring		•		
Glass-thermopack line	Cardboard tote, PET film	g./FU	9.33	On-field monitoring	•			
Product distribution	Transport	tkm	variable	Ecoinvent database, On-field monitoring	•	•	•	•
Waste collection	Transport	tkm	variable	Ecoinvent database	•	•	•	•
EOL treatments	Transport, Energy	tkm-kWh/FU	variable	Ecoinvent database, ARPA, Eurostat	•	•	•	•

Life cycle impacts



	Global warming	Ozone layer depletion	Photochemical oxidation	Acidification	Eutrophication	Non renewable, fossil
	kg CO2 eq	mg CFC-11 eq	g C2H4	g SO2 eq	g PO4--- eq	MJ eq
Scenario 1	0,01004	0,00080	0,00306	0,04622	0,00290	0,15295
Scenario 2	0,00613	0,00049	0,00187	0,02824	0,00177	0,09347
Scenario 3	0,02384	0,00213	0,00693	0,09274	0,00589	0,37278
Scenario 4	0,02413	0,00216	0,00702	0,09406	0,00597	0,37716

Another life cycle assessment example

Contents lists available at ScienceDirect

Journal of Hazardous Materials

journal homepage: www.elsevier.com/locate/jhazmat

Secondary environmental impacts of remedial alternatives for sediment contaminated with hydrophobic organic contaminants

Yongju Choi[a,*], Jay M. Thompson[b], Diana Lin[b], Yeo-Myoung Cho[b], Niveen S. Ismail[b], Ching-Hong Hsieh[b], Richard G. Luthy[b]

[a] *Department of Civil and Environmental Engineering, Seoul National University, Seoul 151-744, South Korea*
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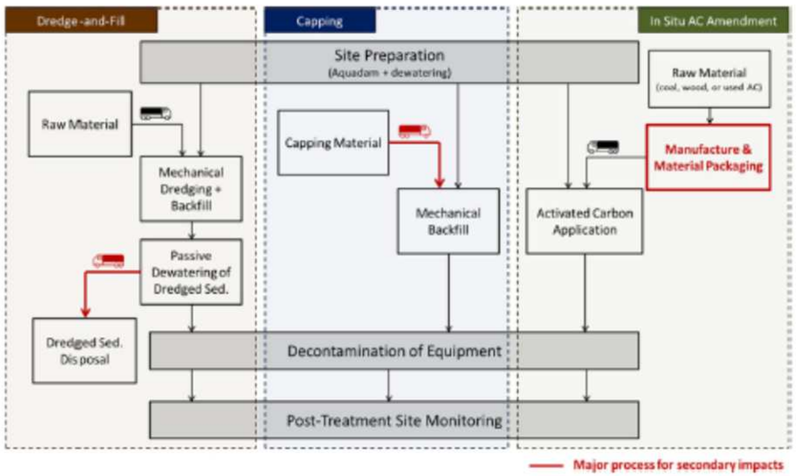
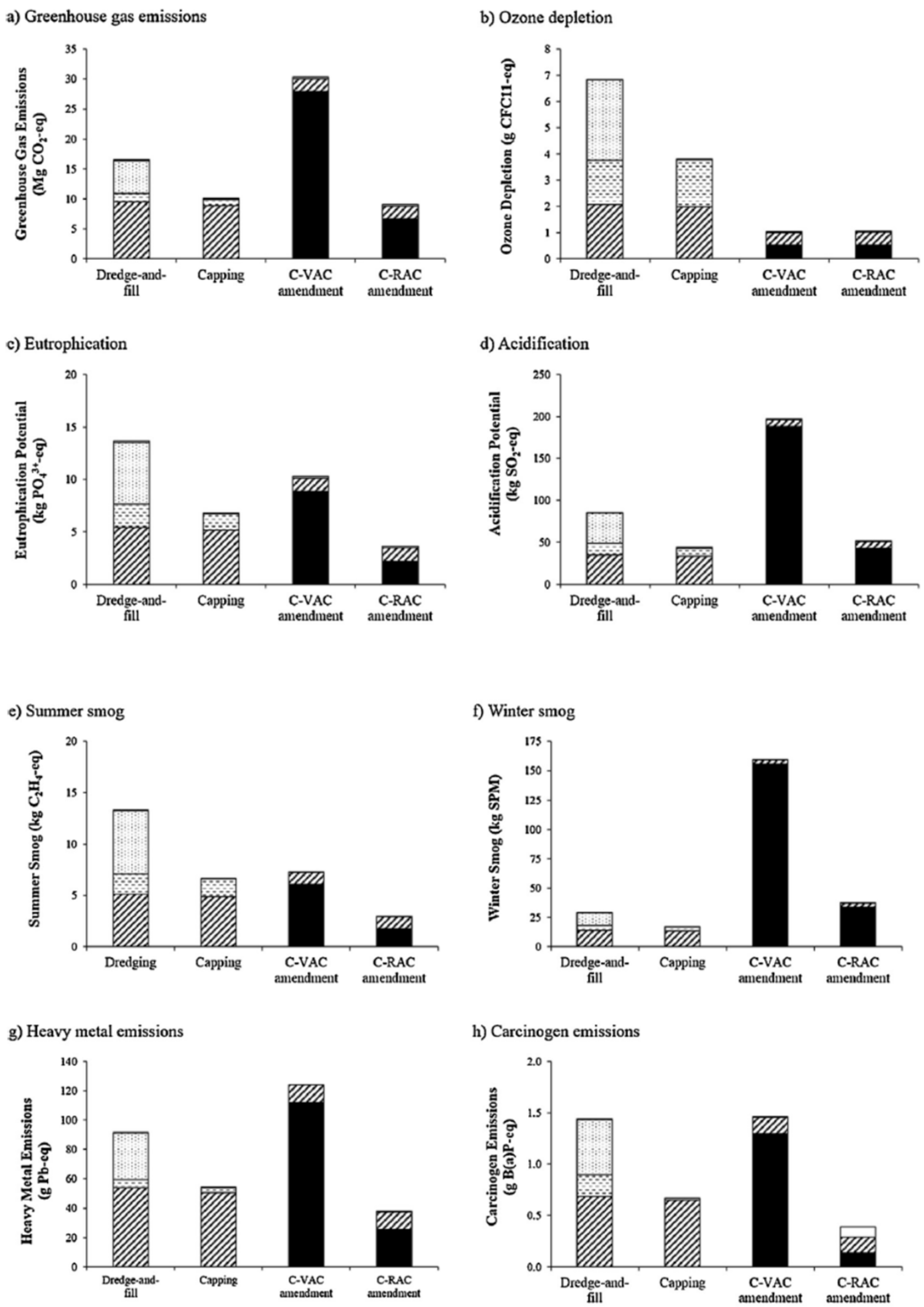
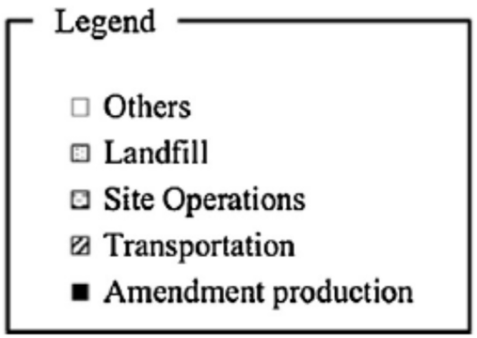
HIGHLIGHTS

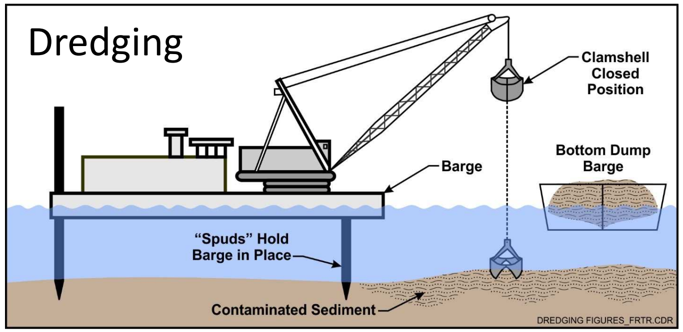
- Compared secondary environmental impacts for sediment remediation alternatives.
- Studied different types and source materials for activated carbon amendment.
- Sorbent production as a major impact contributor for in-situ amendment.
- Minimize impacts of in-situ amendment by using recycled or bio-based sorbents.
- LCA results sensitive to the transport distance for dredging and capping.

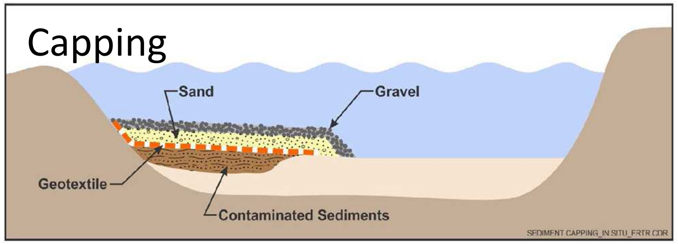
GRAPHICAL ABSTRACT











C-VAC/C-RAC amendment

C-VAC: coal-based virgin activated carbon

C-RAC: coal-based recycled activated carbon

Suggested readings

[ENG] pp. 319 – 322, 345 – 366

[KOR] pp. 307 – 310, 335 – 351

Next class

Water treatment I

- Water treatment process – overview
- Coagulation & flocculation
- Softening