# Gjenvinning av næringsstoffer - resultater fra RECOVER prosjektet

Herman Helness (SINTEF), Blanca M. Gonzalez Silva (NTNU), Stein W. Østerhus (NTNU), Kamal Azrague (SINTEF), Gema Raspati (SINTEF), Willy Thelin (SINTEF)

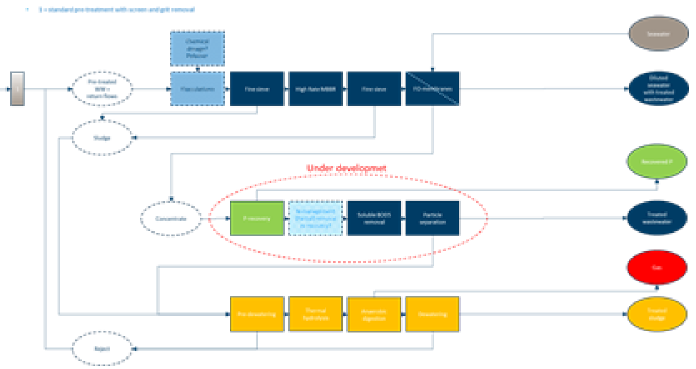
# Kan man gjenvinne næringsstoffer fra slam?

- RECOVER svarer ja, men man må vurdere helheten
- RECOVER: Forskningsrådet, KPN 2015-2020; FoU-partnere: NTNU, NMBU, SINTEF; Industripartnere: CAMBI, DOSCON, Kemira, Küger Kaldnes, Norconsult, Salsnes Filter. Samarbeid med Norsk Vann, HIAS, IVAR, VEAS, m.fl.
- I RECOVER
  - Prosessløsninger for behandling av avløpsvann
  - Prosessløsninger for behandling av slam
  - Prosessløsninger for gjenvinning av energi og næringsstoffer (N og P)
  - Overvåking og styring av prosessløsninger bl.a. med "soft sensors"
  - Vurderinger av total prosess for et tenkt eksempelanlegg
  - Litteraturstudier og forsøk i avløpslabben med både avløpsvann og slam
- Vekt på slam og gjenvinningsalternativene i presentasjonen i dag

# Brief summary of approach used in RECOVER

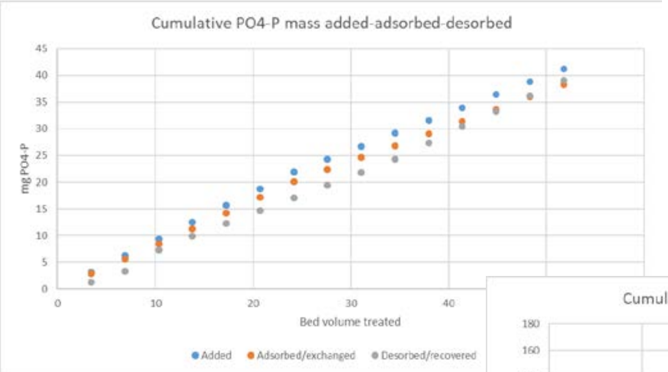
- Base case for the evaluations with wastewater quality corresponding to reported 2015 averages for all Norwegian wastewater treatment plants
- Process schemes for municipal wastewater
  - Reference designs – typically used in Norway, but also to include what is used internationally
  - Innovative designs – new(er) solutions, implemented or with evidence of performance from testing
  - New, potentially future designs - solutions with high potential but with knowledge gaps requiring research
- Screening – size, resource use and potential for recovery of C, N and P – combined with discussions at consortium meetings led to selection of 4 alternatives for wastewater treatment and 4 alternatives for sludge treatment
- Recovery of N and P included according to the process schemes

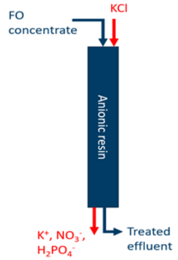
| | | |
|---|---|---|
| Qdesign | 1000.00 | m3/hour |
| Flow, Q | 277.78 | L/sec |
| BOD5/COD | 0.39 | [ .. ] |
| FCOD/COD | 0.37 | [ .. ] |
| NH4-N/Tot-N | 0.67 | [ .. ] |
| PO4-P/Tot-P | 0.67 | [ .. ] |
| | | |
| SS | 221.00 | mg/L |
| COD | 494.00 | mg/L |
| FCOD | 182.78 | mg/L |
| BFCOD | 147.78 | mg/L |
| BOD5 | 195.00 | mg/L |
| FBOD5 | 72.15 | mg/L |
| Tot-N | 37.00 | mg/L |
| NH4-N | 24.67 | mg/L |
| Tot-P | 5.00 | mg/L |
| PO4-P | 3.33 | mg/L |



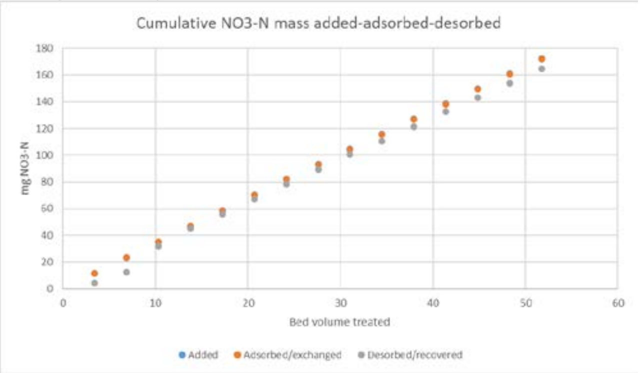
# Recovery options assessed in RECOVER

- **Phosphorus:**
  - Struvite (magnesium-ammonium-phosphate)
    - Optimize struvite crystallization, use of alternative magnesium source
  - Precipitation of calcium phosphate
    - Optimal process conditions
  - Ion exchange
    - Liquid phosphate containing product from regeneration
    - Resin type, optimal regeneration



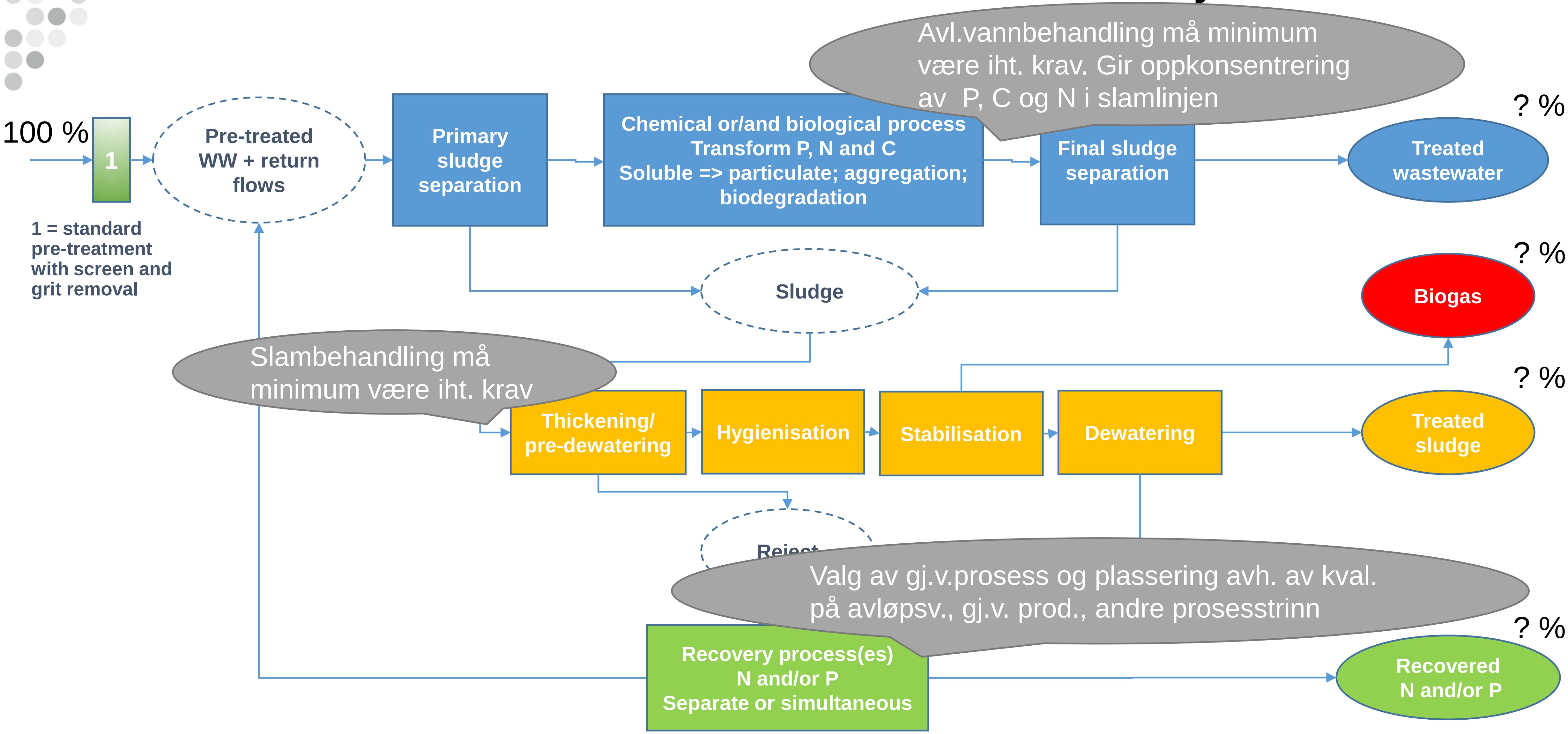




- **Nitrogen:**
  - Stripper – absorber
    - Ammonia sulphate, ammonia nitrate, ammonia phosphate
  - Ion exchange
    - Liquid ammonia or nitrate containing product from regeneration
  - Ammonia is part of struvite

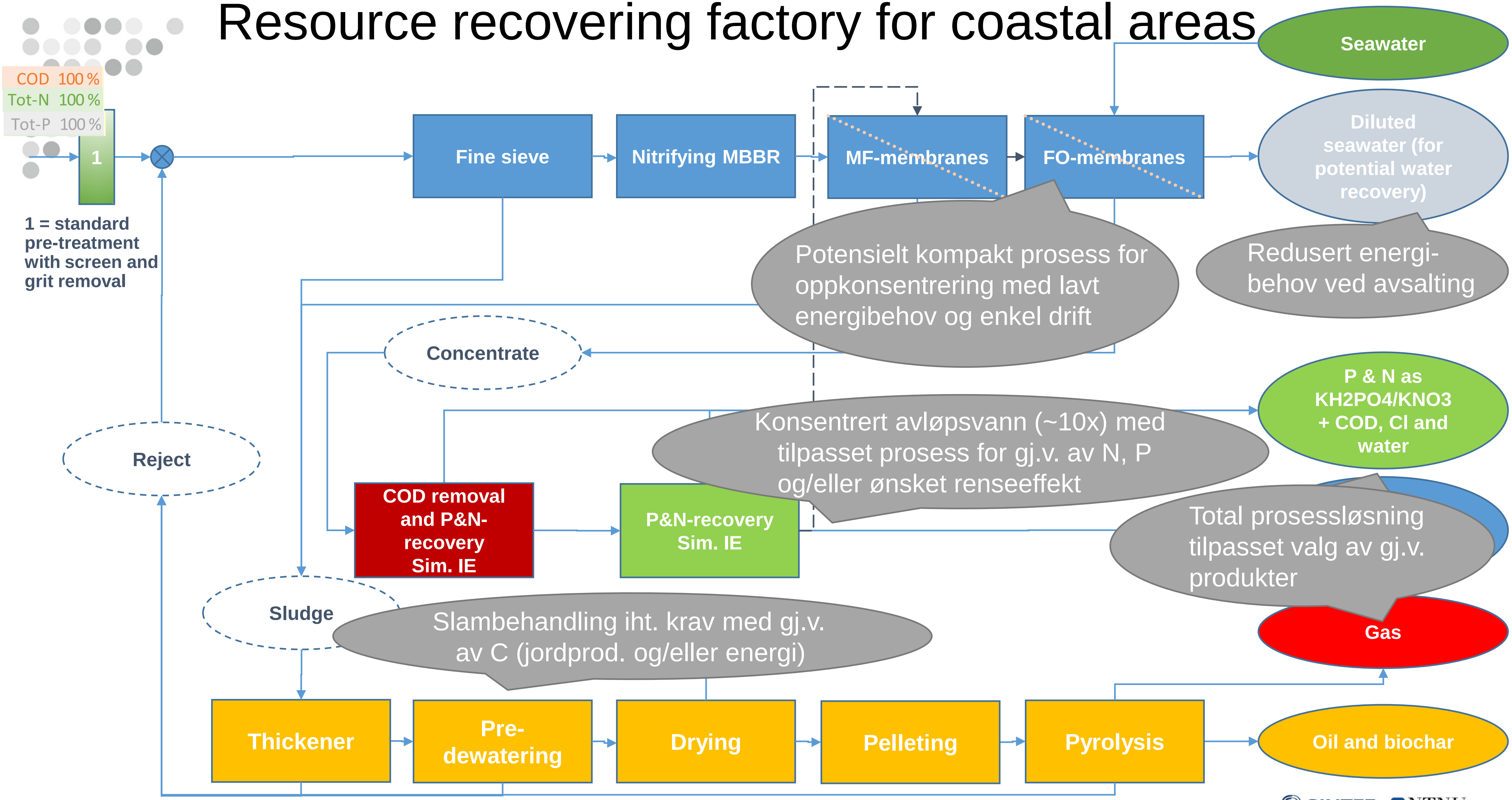



- **Carbon:**
  - Anaerobic digestion
    - Biogas
  - Pyrolysis
    - Gas, oil, biochar

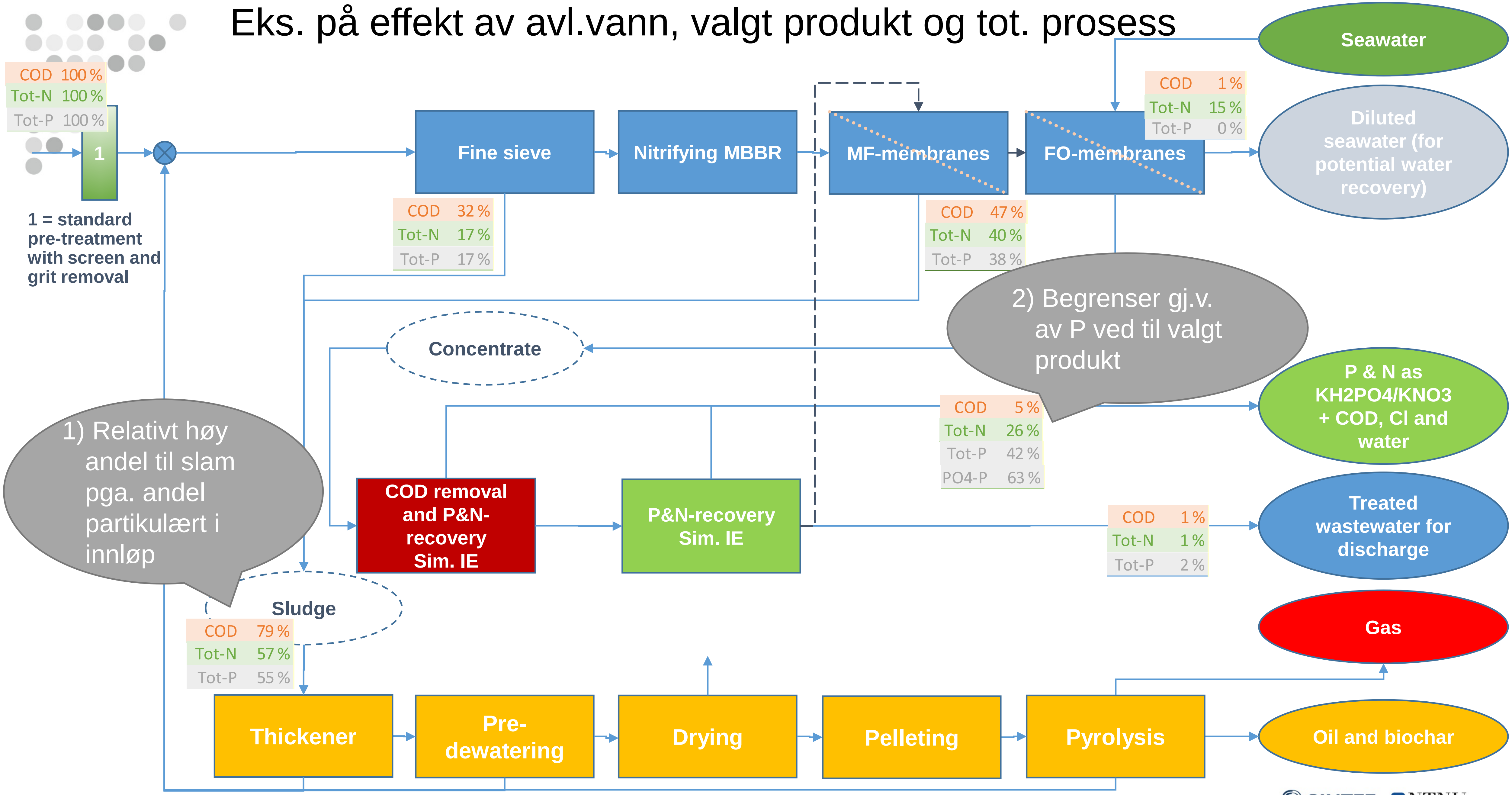
# Generalised WWTP with nutrient recovery



# Resource recovering factory for coastal areas



# Eks. på effekt av avl.vann, valgt produkt og tot. prosess



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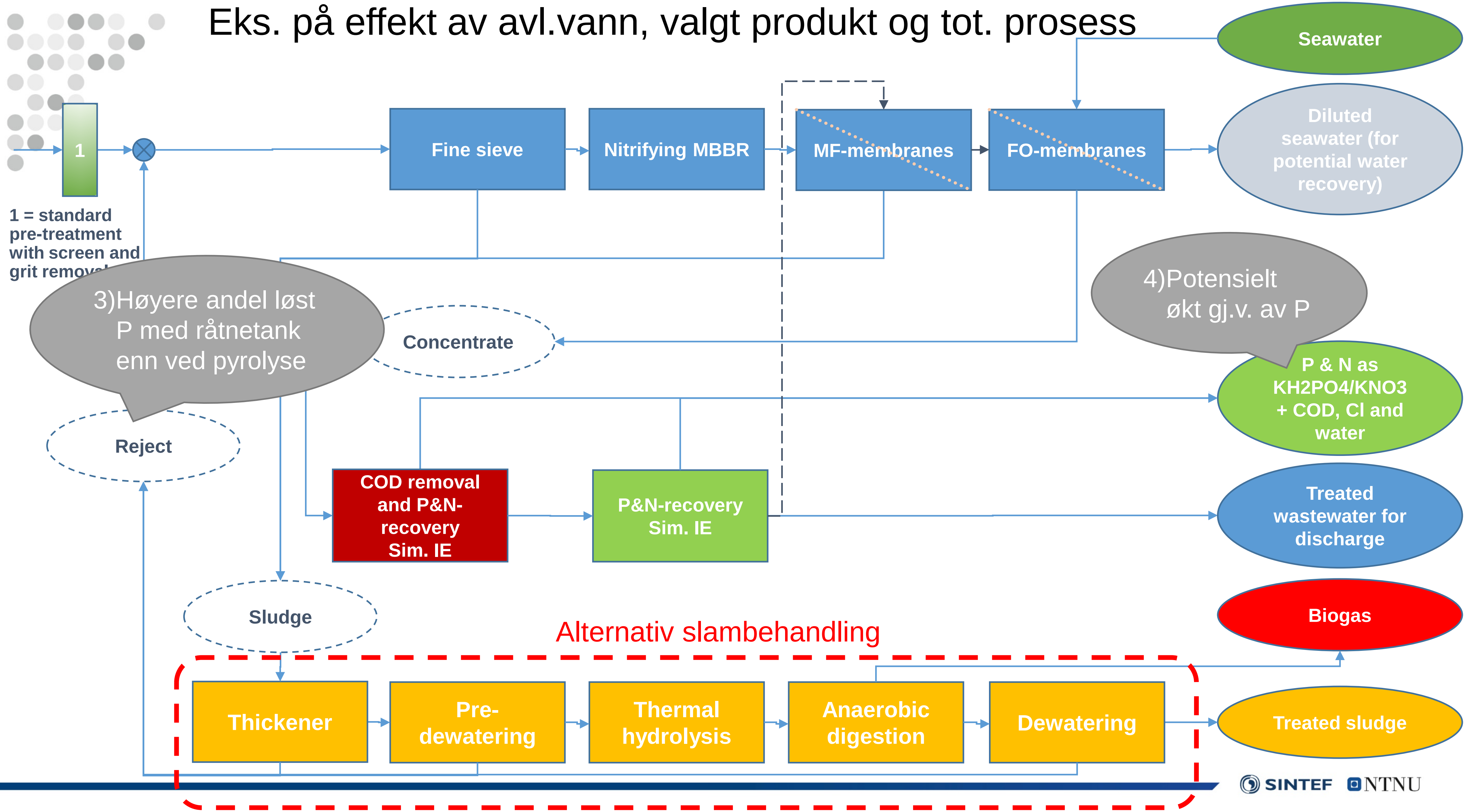


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# Hvordan vurdere og velge total prosess?

- Gjenvinningsgrad avhenger av:
  - Kvalitet på avløpsvannet
  - Prosessløsninger i de ulike delene av anlegget
  - Gjenvinningsprodukt(er)
- Gjenvinning av næringsstoffer og energi – ikke næringsstoffer
  - Avveining av hva som er viktigst av C, N og/eller P
  - Mengde ferdig behandlet slam
- Krever helhetlig vurderinger
  - Multikriterieanalyse og LCA

# Wastewater treatment alternatives

Reference designs:

1. *Chemical phosphorus removal with phosphorus (P) remaining in sludge*
2. Enhanced biological phosphorus removal (EBPR) in activated sludge
3. Biological nutrient removal (BNR) in activated sludge

Innovative designs i.e., new(er) solutions, implemented or with evidence of performance from testing:

4. EBPR with fine sieve, continuous moving bed biofilm reactor (MBBR) and flotation
5. ***BNR with fine sieve, continuous moving bed biofilm reactor (MBBR) and flotation***
6. EBPR in a membrane activated sludge bioreactor (MBR)
7. ***BNR in a membrane activated sludge bioreactor (MBR)***
8. High rate MBBR for C removal and max biogas production with chemical P-removal
9. MBR for C removal and max biogas production with chemical P-removal

New, potentially future designs i.e., solutions with high potential but with knowledge gaps requiring research:

10. ***Biological – chemical process with fine sieve and forward osmosis (FO) membrane.***

# Sludge treatment alternatives

With anaerobic digestion for biogas production:

1. *Thickening + Pasteurization (P) + Anaerobic digestion (AD) + Dewatering (DW)*
2. Thickening + Thermofil AD (T-AD) + Dewatering (DW)
3. ***Thickening + Pre-dewatering (pre-DW) + Thermal hydrolysis (THP) + AD + DW***
4. ***Thickening + Solid stream AD + pre-DW + THP + DW***

Sludge minimalization:

5. ***Thickening + DW + Drying (D) + Pelletization (Pe) + Pyrolysis (pyro)***
6. Thickening + DW + Drying (D) + Pelletization (Pe) + Torrefaction (To)
7. Thickening + DW + Drying (D) + Incineration (In)
8. Thickening + AD + DW + Drying (D) + Pelletization (Pe) + Pyrolysis (pyro)
9. Thickening + SolidStream AD + pre-DW + THP + D + Pe + Pyrolysis (pyro)

# Selected process combinations and criteria

| **Process comnbinations** | |
|---|---|
| Chem P-removal + THP & AD | A+3 |
| Chem P-removal + SolidStream | A+4 |
| Chem P-removal + Pyrolysis | A+5 |
| BNR in continous MBBR + THP & AD | B+3 |
| BNR in continous MBBR + SolidStream | B+4 |
| BNR in continous MBBR + Pyrolysis | B+5 |
| BNR in MBR + THP & AD | C+3 |
| BNR in MBR + SolidStream | C+4 |
| BNR in MBR + Pyrolysis | C+5 |
| FO-design w/nitrifying MBBR + THP & AD | D+3 |
| FO-design w/nitrifying MBBR + SolidStream | D+4 |
| FO-design w/nitrifying MBBR + Pyrolysis | D+5 |

**Inputs**

- Energy
- Chemicals
- Aeration

**Process units**

- Volume
- Size
- HRT

**Outputs**

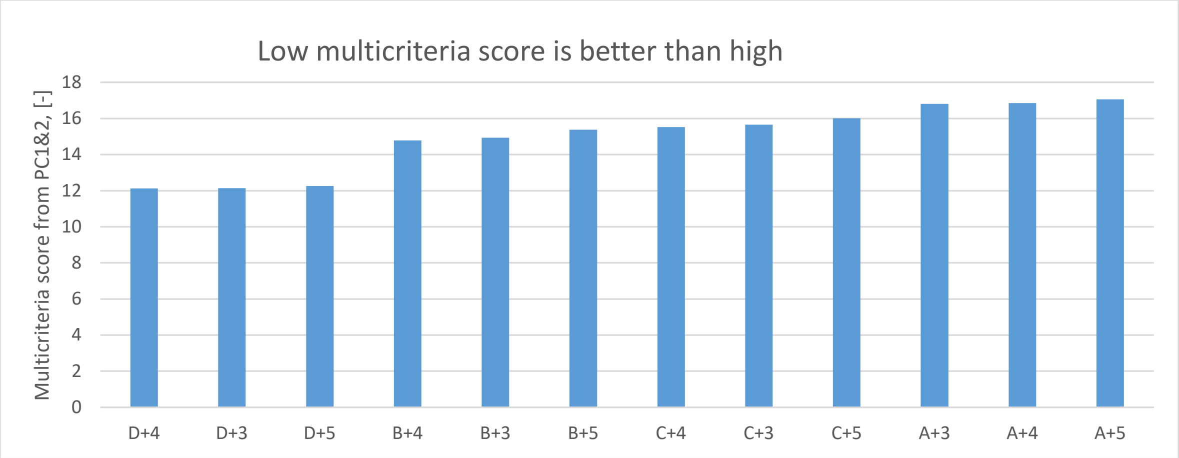
- Energy
- Recovered nutrients
- Biosolids
- Flowrates and concentrations

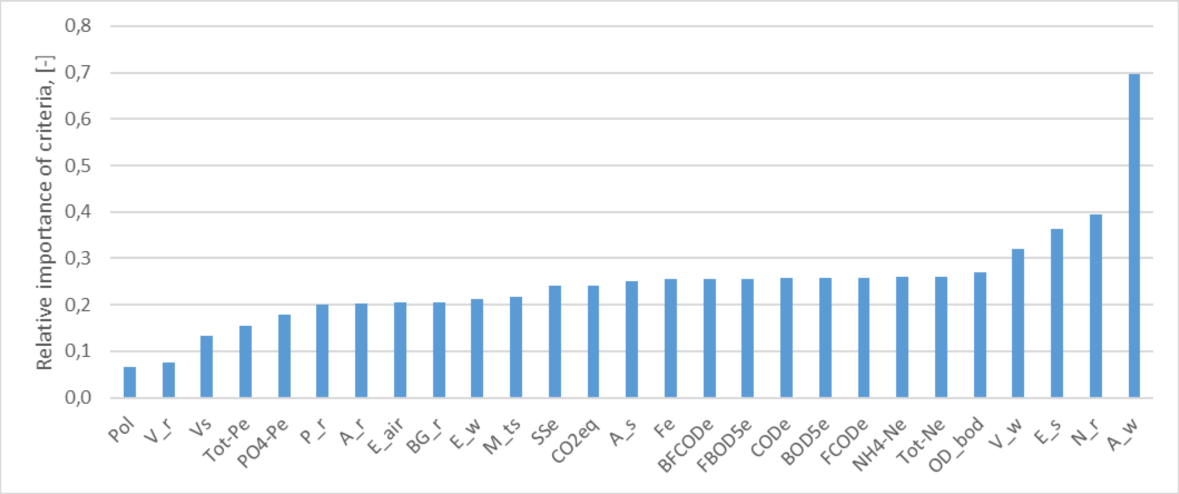
| | |
|---|---|
| Area WWT, [m2] | A_w |
| Wet vol. WWT, [m3] | V_w |
| Dosage of coagulant, [mg Fe/L] | Fe |
| Dose of polymer in WWT, [g Pol/m3] | Pol |
| Energy input for aeration, [kWh/m3] | E_air |
| Sum energy contributions, [kWh/m3] | E_w |
| Carbonaceous O2 consumption rate, [kgO/m3] | OD_bod |
| Effluent conc. mg/L | SS, C, N & P |
| Area sludge treatmetn, [m2] | A_s |
| Volume sludge treatmetn, [m3] | Vs |
| Electricity consumption (Total)KWh/day | E_s |
| Treated sludge or biochar, [kgTS/m3] | M_ts |
| Biogas potential, [Nm3/m3] | BG_r |
| Area recovery proc., [m2] | A_r |
| Volume recovery proc., [m2] | V_r |
| Reoverd N [kg/m3] | N_r |
| Reoverd P [kg/m3] | P_r |
| CO2 eq. [g/m3] | CO2eq |

**Basis:** Norsk Vann design guidelines (2020), information from technology suppliers and experimental results supplemented with literature data

# Example of multicriteria comparison

- NB: Benefits from downstream use of recovered resources not included in this example
- Relatively small differences, FO based alternatives (D) score slightly better
- However, the FO-alternative is at R&D stage and not commercially available
- WWT area, recovered N, and energy for sludge treatment are most influential criteria
- Adding resource recovery comes at a cost (money, energy, area, etc.) that must be compensated by benefits from use of the recovered resources
- Benefits will be case specific and include priorities of stakeholders



# Evaluated scenarios including benefits from recovery

| WWT | Sludge management | Recovery | Final disposal |
|---|---|---|---|
| Chem P | - Meso AD-Pasteurization<br>- THP & AD<br>- SolidStream<br>- Pyrolysis | -> Through agri. Spreading<br>-> Through agri. Spreading<br>-> Through agri. Spreading<br>-> Fuel (biochar, oil, syn. gas) | -> Agriculture<br>-> Agriculture<br>-> Agriculture<br>-> transport to pyrolysis facility or residual waste (ashes) disposal not included |
| BNR-MBBR | - THP & AD<br>- SolidStream<br>- Pyrolysis | -> N & P + agri. spreading<br>-> N & P + agri. Spreading<br>-> Fuel (biochar, oil, syn. gas) | -> Agriculture<br>-> Agriculture<br>-> transport to pyrolysis facility or residual waste (ashes) disposal not included |
| BNR-MBR | - THP & AD<br>- SolidStream<br>- Pyrolysis | -> N & P + agri. spreading<br>-> N & P + agri. Spreading<br>-> Fuel (biochar, oil, syn. gas) | -> Agriculture<br>-> Agriculture<br>-> transport to pyrolysis facility or residual waste (ashes) disposal not included |
| FO | - THP & AD<br>- SolidStream<br>- Pyrolysis | -> N & P + agri. spreading<br>-> N & P + agri. Spreading<br>-> Fuel (biochar, oil, syn. gas) | -> Agriculture<br>-> Agriculture<br>-> transport to pyrolysis facility or residual waste (ashes) disposal not included |

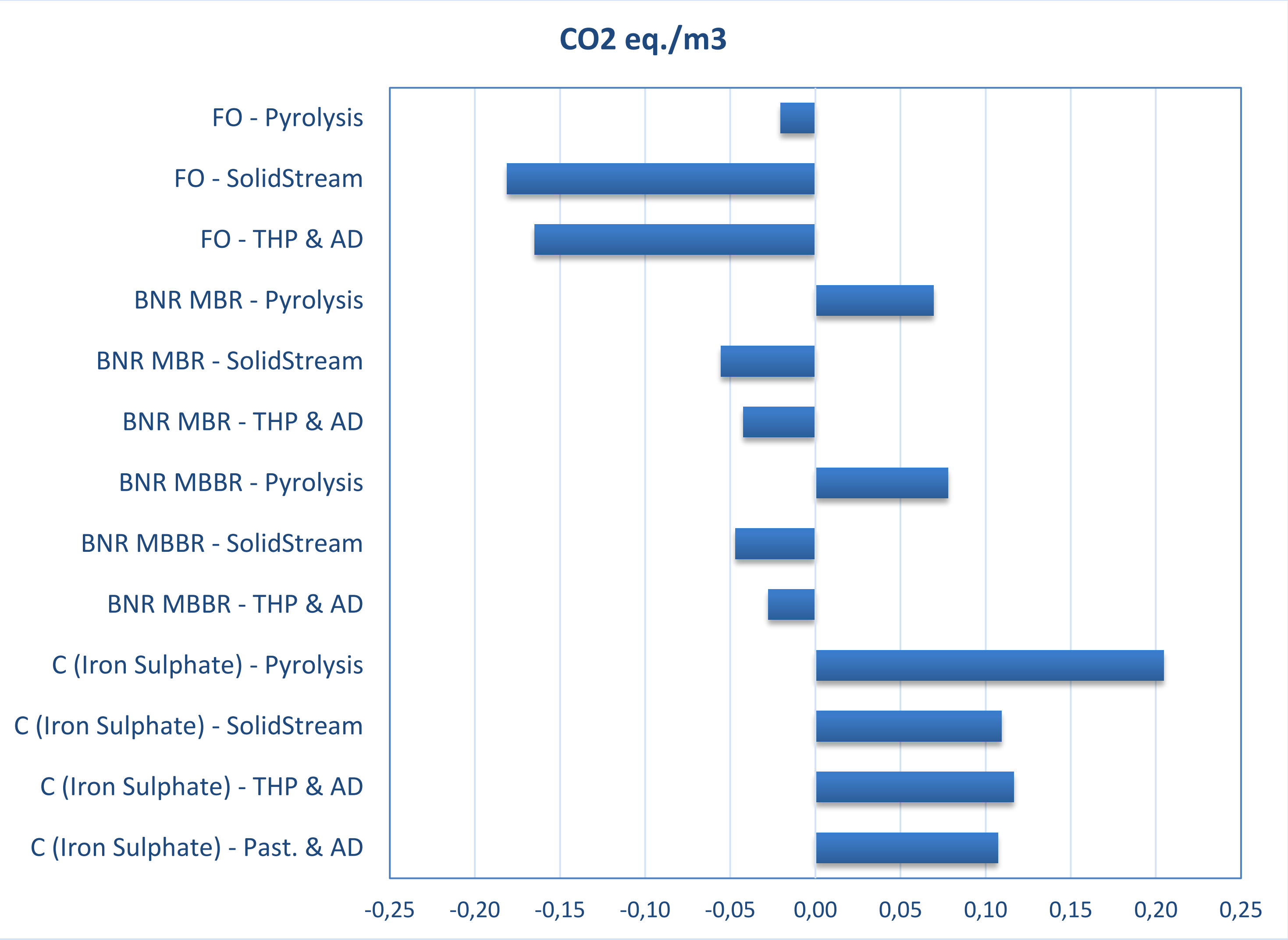
# Life Cycle Assessment of environmental impacts

**LCA (ISO 14040, 2006):**

- SimaPro version 8.5.2.0, methods CML2 and Eco-indicator 99
- Functional unit 1 m3 of raw wastewater
- Construction and operation phase included
- NORDIC electricity mix
- Ecoinvent database

**Global warming (GWP100)**

- $CO_2$ eq./m3: > 0 negative, < 0 beneficial
- Main emissions from effluent, sludge, use chemicals and construction of buildings
- Main grouping: Chemical > biological > FO
  - Chemical and biological are commercially available, FO at R&D stage
- Secondary grouping: Pyrolysis > biogas + N&P
  - Drying of sludge
- SolidStream slightly lower GWP than THP & AD



# Life Cycle Assessment of environmental impacts

## Eco-indicator as milli points (mPt)

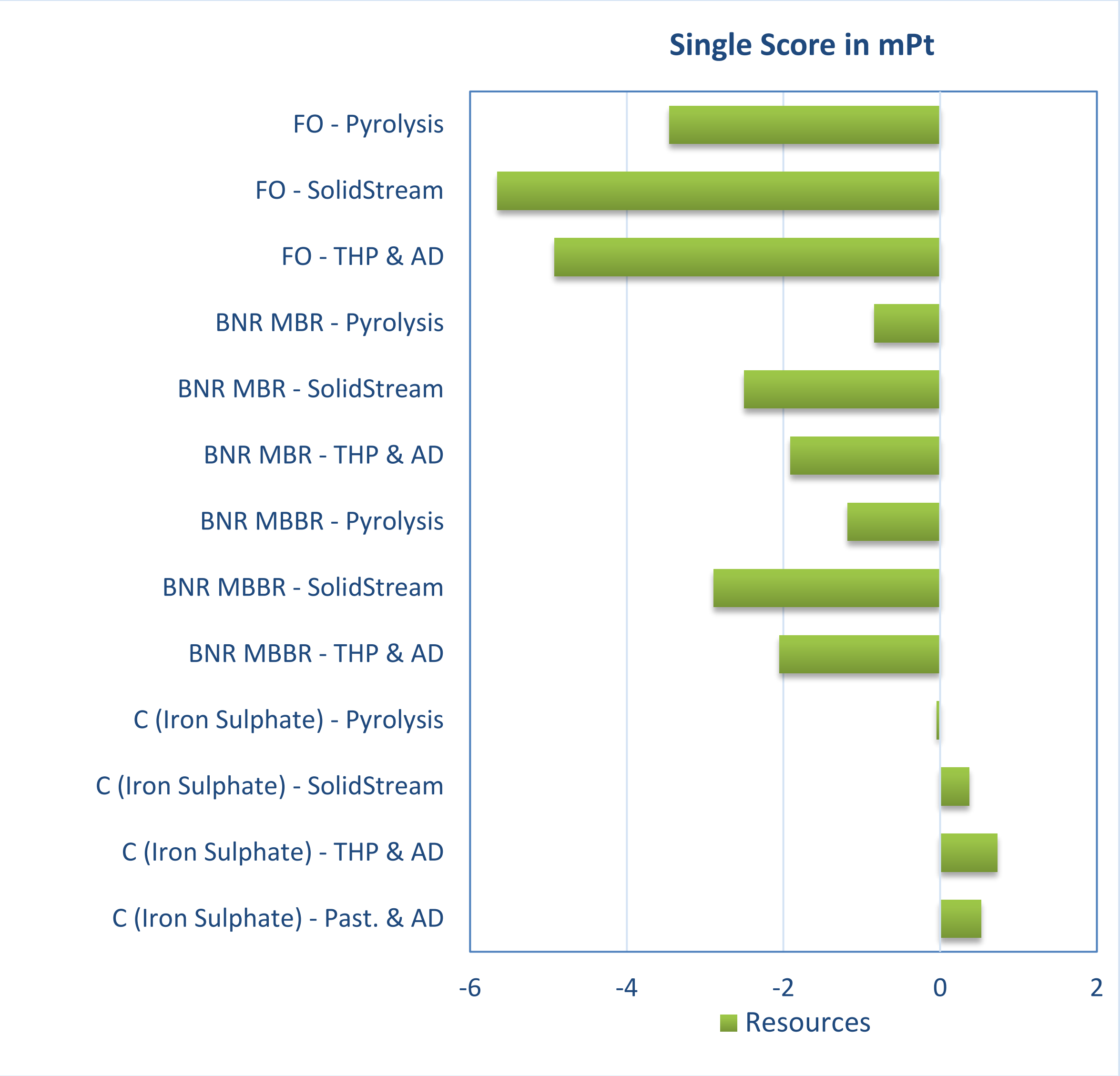
- Representative for the yearly environmental load of one average European inhabitant.
- Used for relative comparisons
- Calculated for several categories, the figure shows results for 'resources'

## Resources (mPt)

- mPt > 0 negative, < 0 beneficial
- Same main and secondary grouping with respect to impact on resources as for GWP
- Main contributions from use of minerals and fossil fuel associated with chemicals, construction and energy

## Other categories

- Impacts calculated also for 'human' and 'ecosystem'
- Used chemicals (coagulant, polymer and recovery chemicals), drying and construction



# Oppsummering fra RECOVER

- Det finnes flere kommersielt tilgjengelige prosessalternativer for gjenvinning av næringsstoffer
- Gjenvinning av næringsstoffer og energi – ikke bare om næringsstoffer
  - Avveining av hva som er viktigst av C eller N&P
- Gjenvinningsprosessene krever areal, volum og ressurser (energi, kjemikalier) som må oppveies av fordelene ved gjenvinning
- Krever klar strategi og verdikjede nedstrøms RA for å velge rett prosesskombinasjon og gjenvinningsprodukt(er).
- Uten realisering av fordelene kan nettoeffekten bli lav i en totalvurdering (klima, miljø, ressurser, størrelse)
- Med en standardisert teoretisk realisering av fordelene kom alternativene med gjenvinning av N & P til gjødsel og biogass til energi best ut i totalvurderingen og i miljøvurderingen
- RECOVER stoppet vurderingen ved porten til RA
- Nedstrøms verdikjeder med eksempelstudier inkludert i WIDER UPTAKE (EU-prosjekt, startet i 2020)