Our drive is the human being in its environment.

# Integrative landfill site rehabilitation

## including subsequent use for energy generation and green H2 production

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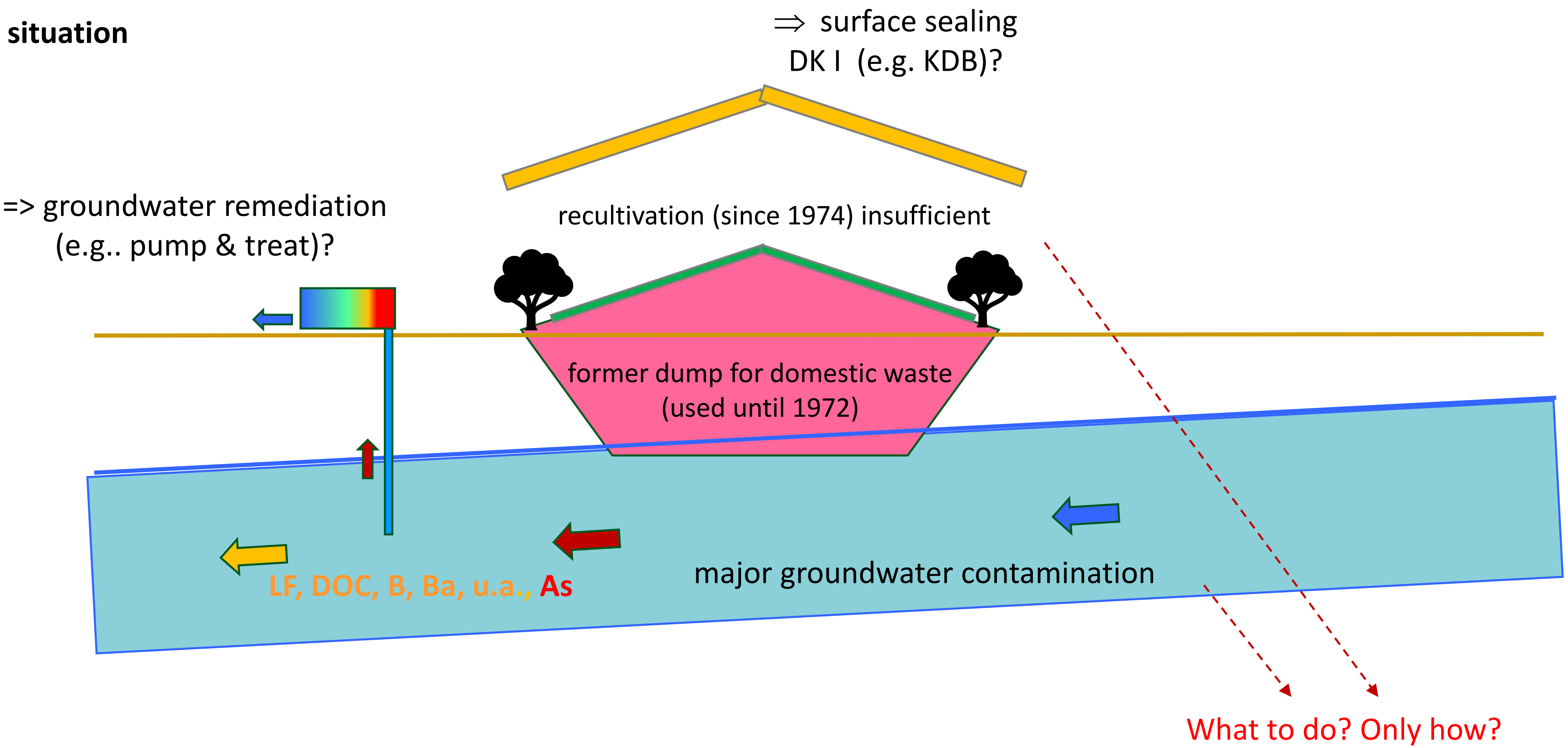
## Outline

**Initial situation**



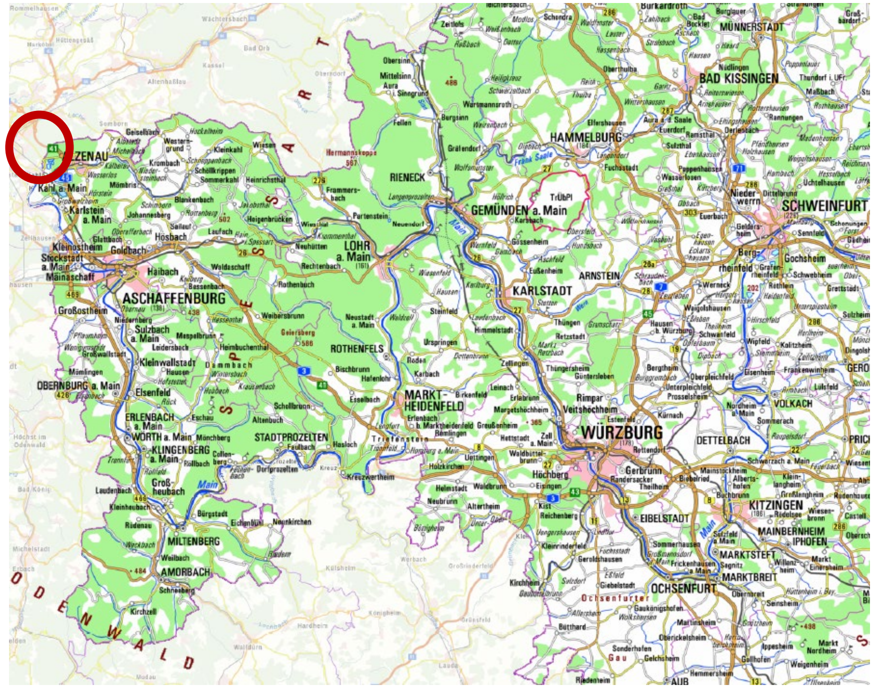
## Outline

1. Problem definition
2. **Key facts: landfill and location**
3. Need for measures
4. Solution approaches
5. Results and outlook

# Integrative landfill site rehabilitation

## Key facts: landfill and location

### Site location
- Lower Main Lowlands, west of the Vorspessart
- Rainfall: about 660 mm/a (low precipation in Bavaria in general)



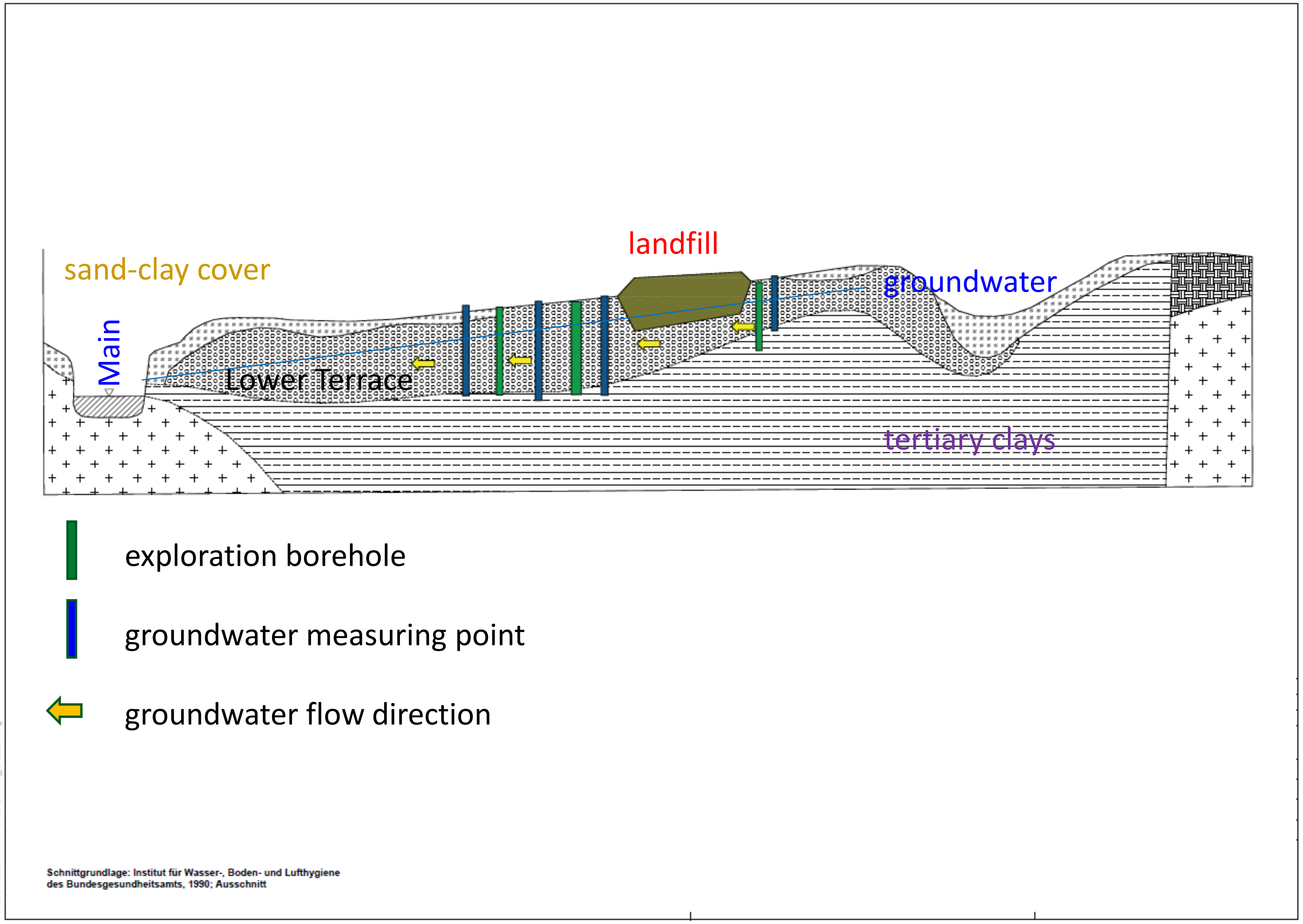
### Topography and neighbouring usages
- Agriculture
- Industrial and commercial use
- Housing ≥ 500 m
- No drinking water protection area in downstream area
- No areas under conservation law

# Integrative landfill site rehabilitation

## Key facts: landfill and location

**Location - hydrogeology**

- Pleistocene Lower Terrace
- Dams made of tertiary clays / alternating layers of clay and sand
- Ca. 8 -10 m thick, sand-gravel Aquifer als *pore ground water conduit*
- Depth of the natural ground water level 4 - 5 m; landfill bottom in contact with groundwater in some areas
- GW-thickness: 3 – 5 m, with approx. 0.4 % gradient aligned with Main, pollutant plume
- *Main 450 m west* of the landfill, regulated by barrage levels



**Landfill – history**

- Since 50s garbage dump in former gravel-sand pit
- 1968: authorized for use as dump for domestic waste, construction waste, bulky waste etc.
- 1972: stop of accumulation
- 1974 et seq.: recultivation: 0,5 m soil application with humus covering, plants appropriate for the site, all incomplete
- Since 80s: ground water monitoring, as one of seven chosen landfills of a pilot project in 1987/88 (BGA, 1990) )
- 1996: study: securing and remedial concept, with further use as earth excavation site, later with partial relocation
- 1999: orientational investigation
- 2010 et seq.: detailed assessment
- 2019: investigation for rehabilitation possibilities
- 2020 MNA-spezific investigation
- 2021 ff. MNA-specific monitoring

## Key facts: landfill and location

**Landfill – characteristic features**

- Flat plateau ca. 2 m above Lower Main Lowlands Plane with high shrubs
- Area of roughly 65.000 m², accumulated debris ca. 300.000 m³
- Depth ca. 4 – 7 m, local deep spots meet ground water (Outcrops; aerial photograph 1962)
- Sedimentations are typical for domestical waste: synthetic material, ceramic, glass, metal, construction waste, possibly industrial waste
- Landfill gas (2011, 2013) in central area (10 Vol.-% $CH_4$), FID mostly < 1 ppm
- For landfill typical impact on the groundwater, special case Arsen
- Rehabilitation incomplete

Key facts: landfill and location

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**Landfill – legal framework**

- Still under aftercare
  → Waste law, not soil protection legislation (Government of lower Franconia, 2009)
- Decommissioning phase (1974 ff.) started before January 1, 1997
  → Landfill ordinance is not legally binding (except for substitute building material regulations (§§14 ff.)), professional guidelines)
- Hazard prevention measures (groundwater, surface coverage)
  → material soil protection regulations
- Time dimension 50 years after end of deposition (1972)
  => principle of proportionality

Target perspective: dismissal from aftercare

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## Integrative landfill remediation

Need for measures

**Rehabilitation** of the landfills surface coverage

- 1974 ff. recultivation:
  - 0,5 m soil application with humus covering
  - site-appropriate plants
  - incomplete
- Current stock:
  - shrubs and woods from the initial rehabilitation
  - growth of succeeding vegetation over the duration of nearly 50 years
  - stock does not comply with the current standard (requirememts of today)


# Integrative landfill remediation

## Need for measures


**Ground water** (impact)

- **Territory**
  - Contaminant plume towards the River Main
  - Lateral borders
- **Material**
  - Typical fingerprint for landfills
    - Conductivity, DOC, ammonium, boron, barium, etc
    - Concentration < level 2 LfW 3.8/1
  - Special case Arsen
    - Concentration > level 2 LfW 3.8/1
    - Only in a certain area close to the landfill
- **Time**
  - Has been stable for years

→ **MNA-potencial**: analysis according to LfU-leaflet 3.8/3 (2015)

# Integrative landfill remediation

## Need for measures

- **Aim**: closure, end of aftercare
  - A) **Rehabilitation** (final closure)
    - **Ground coverage** (ground – human)
      - Complete **rehabilitation** (based on original approval)
    - Extensive measures (complete sealing), if necessary for ground water protection (ground - water)
      - Possibly **surface sealing** e.g. according to DK I standard
  - B) **Ground water** (further measures)
    - Proof of **natural attentuation** (Arsen > Level-2) needed for ground water protection
      - Parameter > level 1: monitoring
      - Parameter > level 2 (As): „**natural attenuation**“
    - Extensive measures and rehabilitation, if necessary
      - Parameter > level 1: monitoring
      - Parameter > level 2: **rehabilitation** (e.g. pump & treat)

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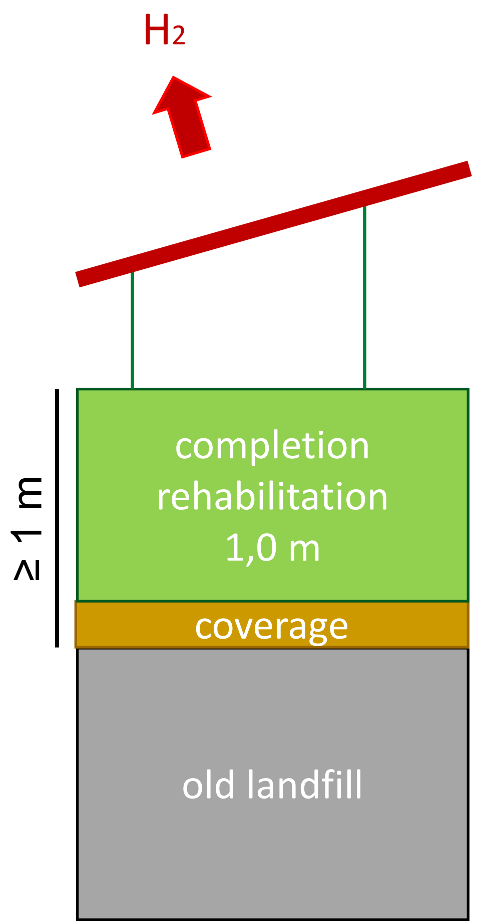
## Solution approaches - recultivation




**Recultivation**

- Completion of the recultivation
  - ≥ 1,0 m ground coverage (without physical cover)
    - Measures pathway ground – human
    - Insofar no extensive requirements pathway soil – ground water
  - Nature conservation inventory and compensation regulations

**Follow-up-use: photovoltaics**

- Area use:
  - Renewable energy
- Synergies
  - Rainwater gathering > minimizes the wash out of contaminants in the landfill
  - Reinfiltation > aid to natural prozesses in the ground water (redox potential)
  - Operator is the ulitity company of the city > production of „ green hydrogen“

# Integrative landfill site rehabilitation

## Solution approaches – groundwater

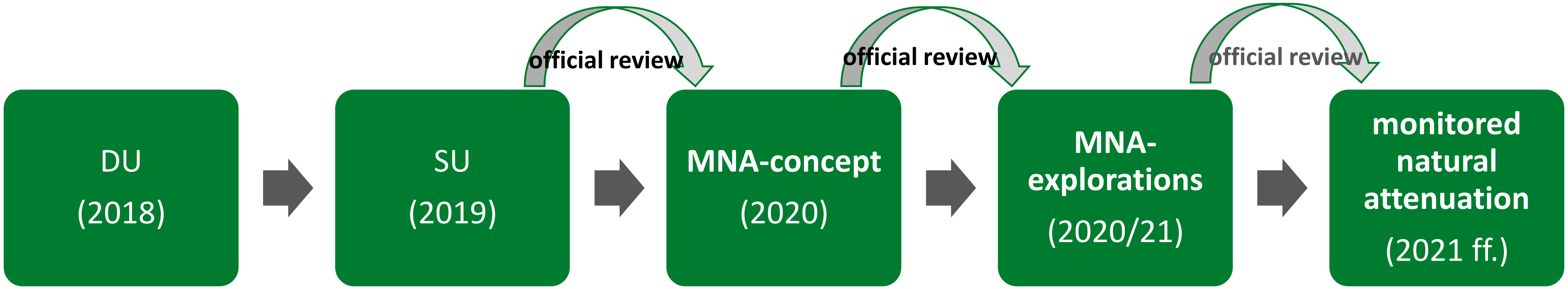
**Groundwater – natural self cleaning processes?**

**NA** – natural attenuation

*„Natural Attenuation“ (NA) or. „Natural Pollutant Reduction “ is unterstood to mean, following the Oswer-Directive of the US-EPA (US EPA OSWER 1999), various biological, physical and chemical processes, that act naturally in soil and groundwater without human intervention and contribute to the reduction of mass, toxicity, mobility, volume and concentration of pollutants there.“ (LfU, 3.8/3).*

**MNA-concept** – site-specific implementation according to LfU 3.8/3 (2015) and preliminary coordination with WWA

**„***The MNA concept extends the SU by a detailed NA-specific exploration (Phase I-III). The NA-specific exploration, together with the variant study for the selection of suitable remediation methods, taking into account proportionality, constitutes the basis of the regulatory decision to implement MNA." (LfU, 3.8/3).*



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**MNA-prerequisites (LfU 3.8/1)**

| Condition of the location LfU 3.8/3, Nr. 2.4 | Condition of the location |
|---|---|
| **Hydrogeological circumstances**<br>• Extensive reconnaissance<br>• With reasonable aim<br>• Usually pore groundwater conduits<br>• No depth displacement | **Lucid hydrogeology**<br>• Quaternary aquifer<br>• Over tertiary dam<br>• With powerful receiving water<br>→ Supplementary MNA-specific subsurface outcrops |
| **contaminant plume**<br>• Area, time period and meterials are known<br>• Stationary | **Long-term investigation**<br>• > Spatial and material deepening<br>• > Semporal continuation of GW monitoring |
| **Minimizing the pollution in the contaminant plume**<br>• Use of prozesses that minimise load<br>• No enrichment with toxic metabilites | **Indications from long-term monitoring (arsenic)**<br>• Adsorption processes decisive<br>• No metabolic degradation of arsenic (≠ LHKW -> vinyl chloride)<br>• > To be verified by MNA-specific investigations |
| **Source intensity**<br>• Decontamination of the contaminant source or<br>• Minimizing ist intensity | **Source strength minimization by**<br>• Rehabilitation<br>• Photovoltaic-follow-up-use, water catchment & drainage |

## Solution approaches – groundwater

**MNA examinations - measuring points**

- Function control of existing measuring points (TV)
- Measuring point compaction in the downstream area
  - 15 exploration wells, thereof
  - 5 new groundwater monitoring wells
- Construction of three observation levels along downstream
  - „0" m level 1
  - 100 m level 2
  - 200 m level 3
- Intensive owner discussions

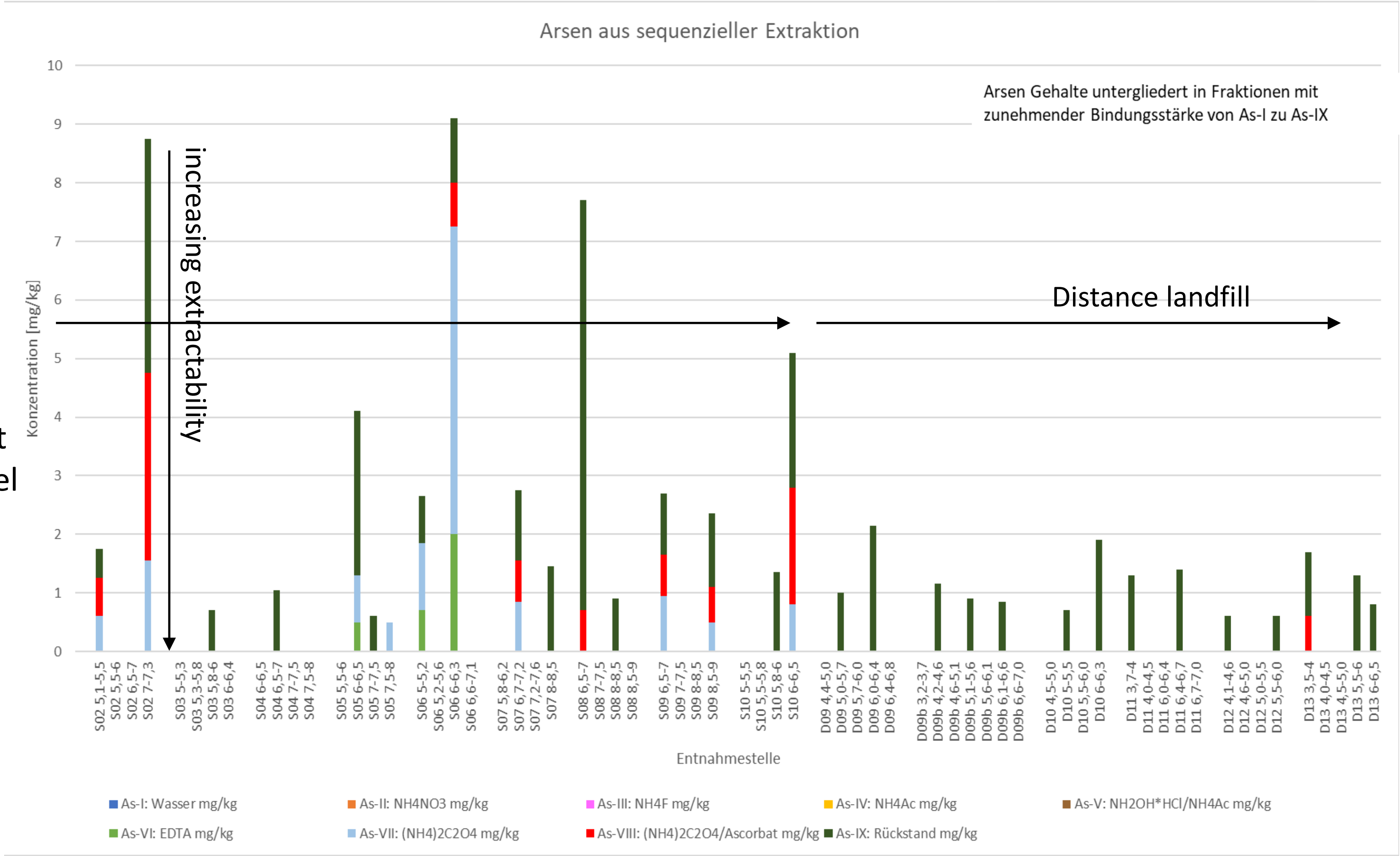
**MNA-examinations – analytic**

- Solid matter analysis (aquifer matrix)
  - Total contents arsenic; iron, manganese; barium (aqua regia digestion):
  - Binding strength arsenic (sequential extraction)
  - Stability iron oxides as adsorbents (oxalate-soluble and dithionite-extractable fractions)
- Groundwater investigations (dissolved contents), e.g.
  - Milieu characterizing: oxygen, redox potential, sulfate, iron, manganese, nitrate
  - Site-typical: ammonium, arsenic, barium, chlorobenzene, DOC, conductivity
  - Arsenic mobility: arsenic species As(III) - As(V)
  - Particulate and dissolved fractions Arsenic: unfiltered - 450 nm - 20 nm filtered

**Solids testing (selection)**

> *Arsenic binding strength*

- Sequential extraction
- 9 extraction agents, e.g.
  level I: water ….
  level VI: EDTA ….
  level IX: aqua regia
- Result:
  - Near landfill (0 – 100 m) but predominantly difficult (level VI, VII, VIII).
  - Far from (200 m) only aqua regia extraction (IX)



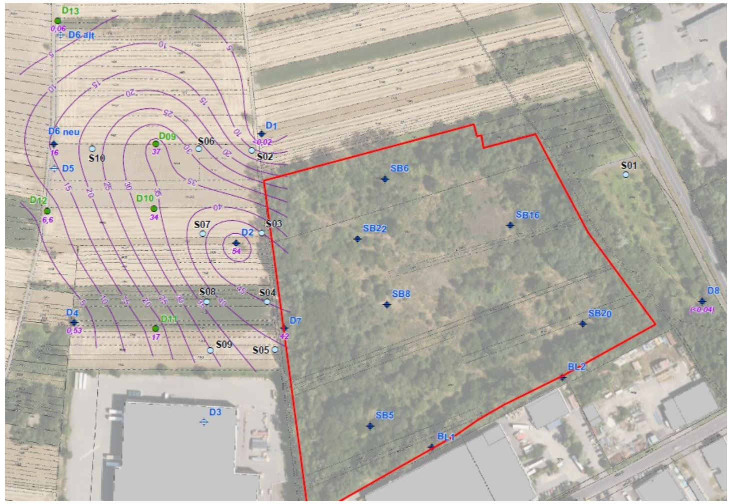
# Integrative landfill site rehabilitation

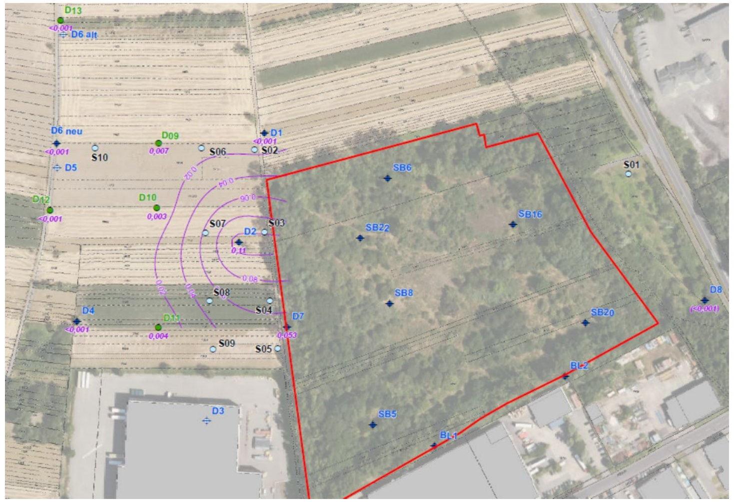
## Solution approaches – groundwater

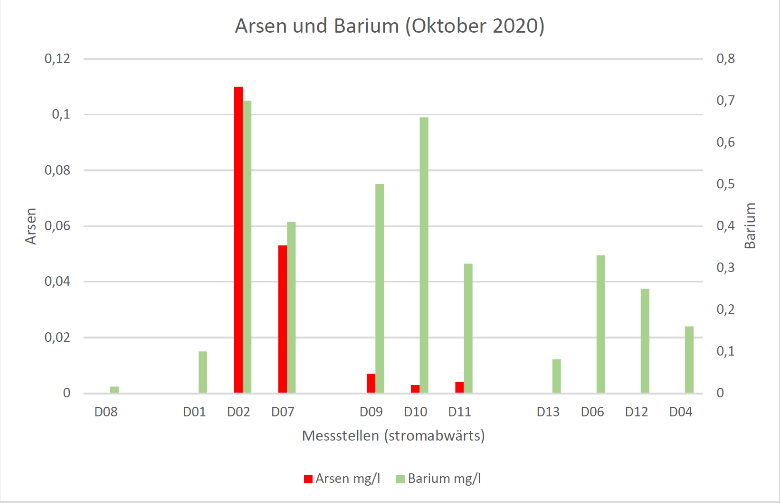
**Groundwater-examinations** (selection)

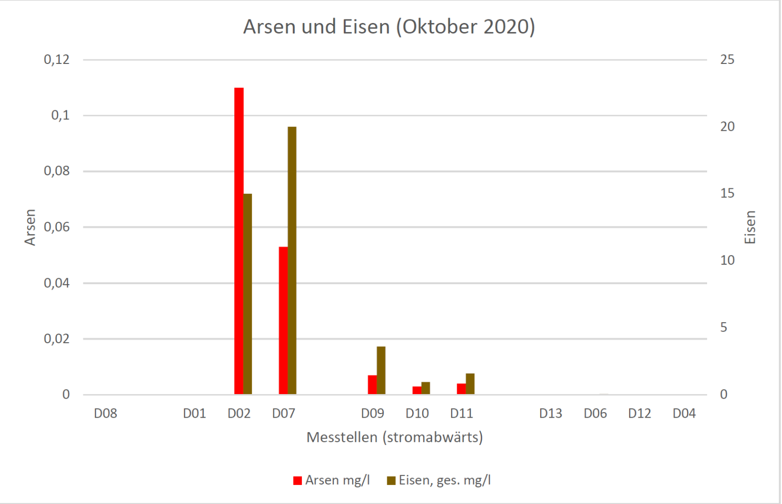
*> correlations (processes)*

- Arsenic – iron
- Not: arsenic – barium (representative for general downstream)
- Result: specific adsorption As on Fe







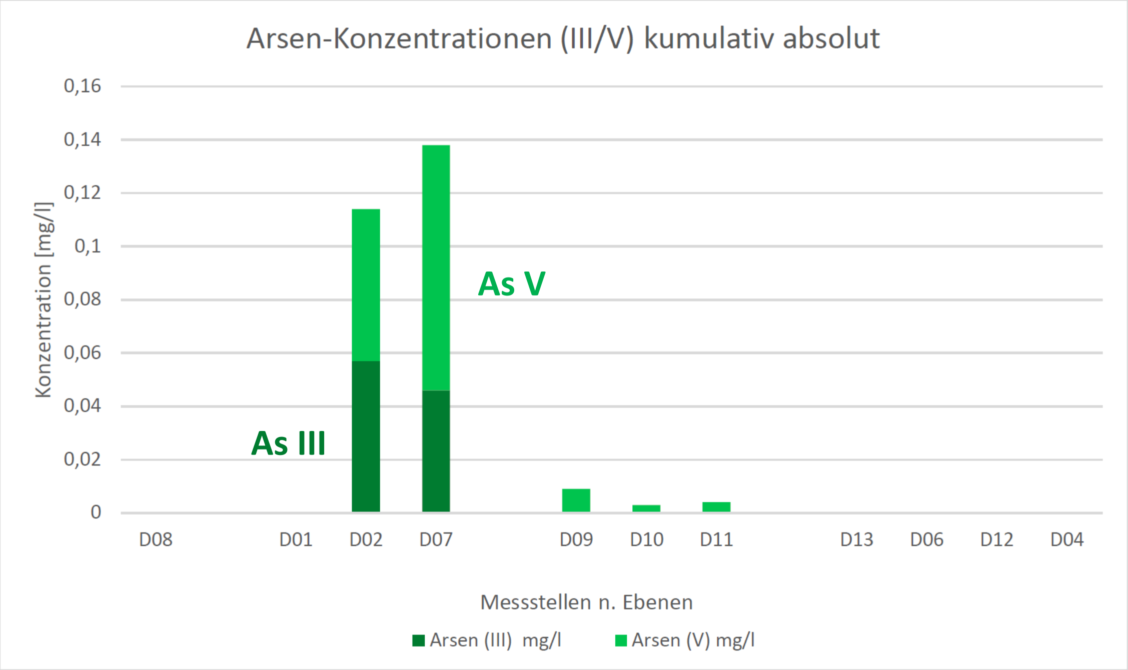
# Integrative landfill site rehabilitation

## Solution approaches – groundwater

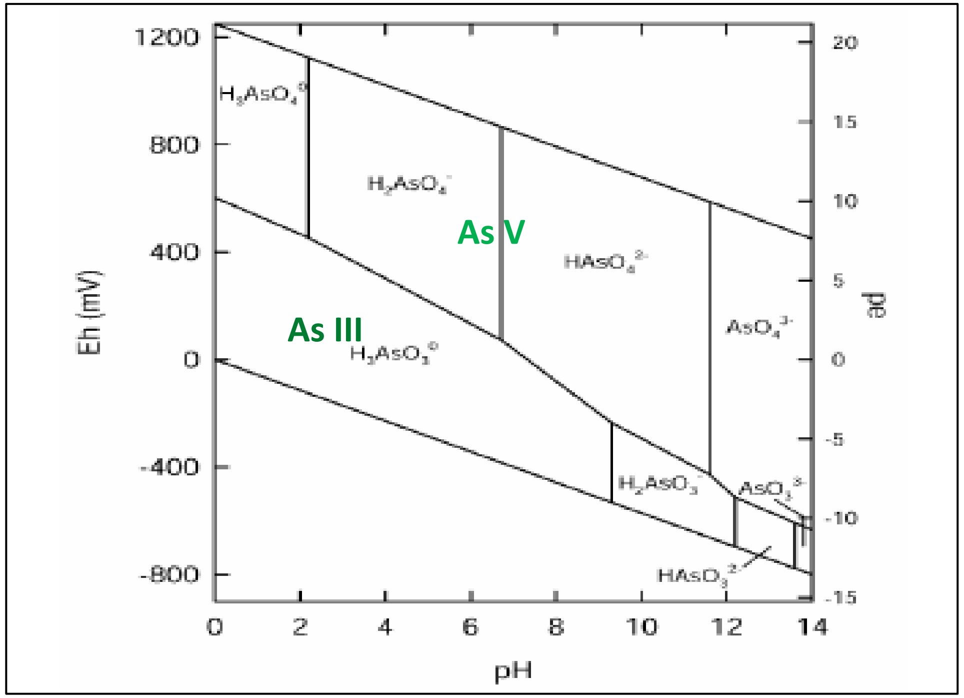
**Groundwater-examination** (selection)

*> mobility arsenic*

- Redox influence on arsenic species (stability diagram) and thus mobility ($As^{III} > As^{V}$ )
- Differentiation of arsenic species $As^{III}$ / $As^{V}$
- Result: $As^{III}$ only near landfill




Eh/pH-stability diagram arsenic-species



**Results of MNA examinations**

- Arsenic load reduction in the effluent by specific fixation processes
  - Adsorption to iron: significant and stable immobilization process
  - Mobility arsenic near landfill and redox sensitive
- Arsenic load in the aquifer near the landfill over 50 since the end of the deposition phase:
  - Ca. 3 – 4 mg/kg,
  - i.e., approximately at the level of the geogenic background concentration.

**Prognosis**:

- No overloading of the natural containment system expected in the foreseeable future.
- Tendency for MNA-promoting redox developments in groundwater effluent (age of deposition).
- Enhancement of MNA-effective processes by subsequent use
- Synergy minimization of material discharge from old landfill (stormwater drainage),
  - Synergy promotion of groundwater processes (redox milieu with precipitation water discharge)
  - Potential "green hydrogen"

## Outline

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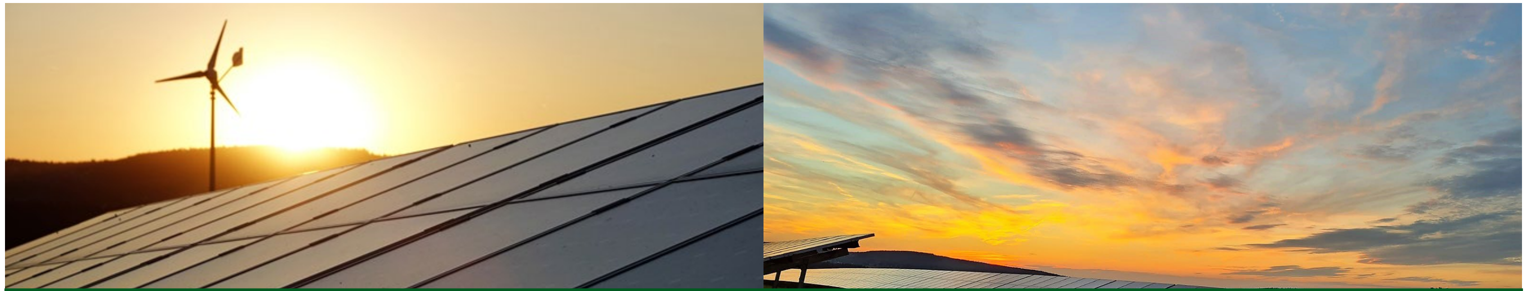
**Key points of an area-wide photovoltaic system**

- Complementary to OFAD over lifetime PV of at least 35-40 years
  → Minimization rain water access: capture and lateral discharge ground water and support natural processes („enhanced natural attenuation“ - ENA)
    → After end of life re-evaluation (follow-up PV?)
- Landfill residual gas
  → Complete coverage (oxidative reduction methane)
  → Cetailed planning
- Vegetation development
  → Sufficient lighting and soil moisture
  → Develop compensation area potential
- Accessibility for maintenance and repair modules,
  → Access corridors, mounting height
- Foundation without landfill interference
  → e.g. installation on foundation beams on surface
- Landscape
  → border integration (also: nature conservation), fencing

**Synergies and potentials**

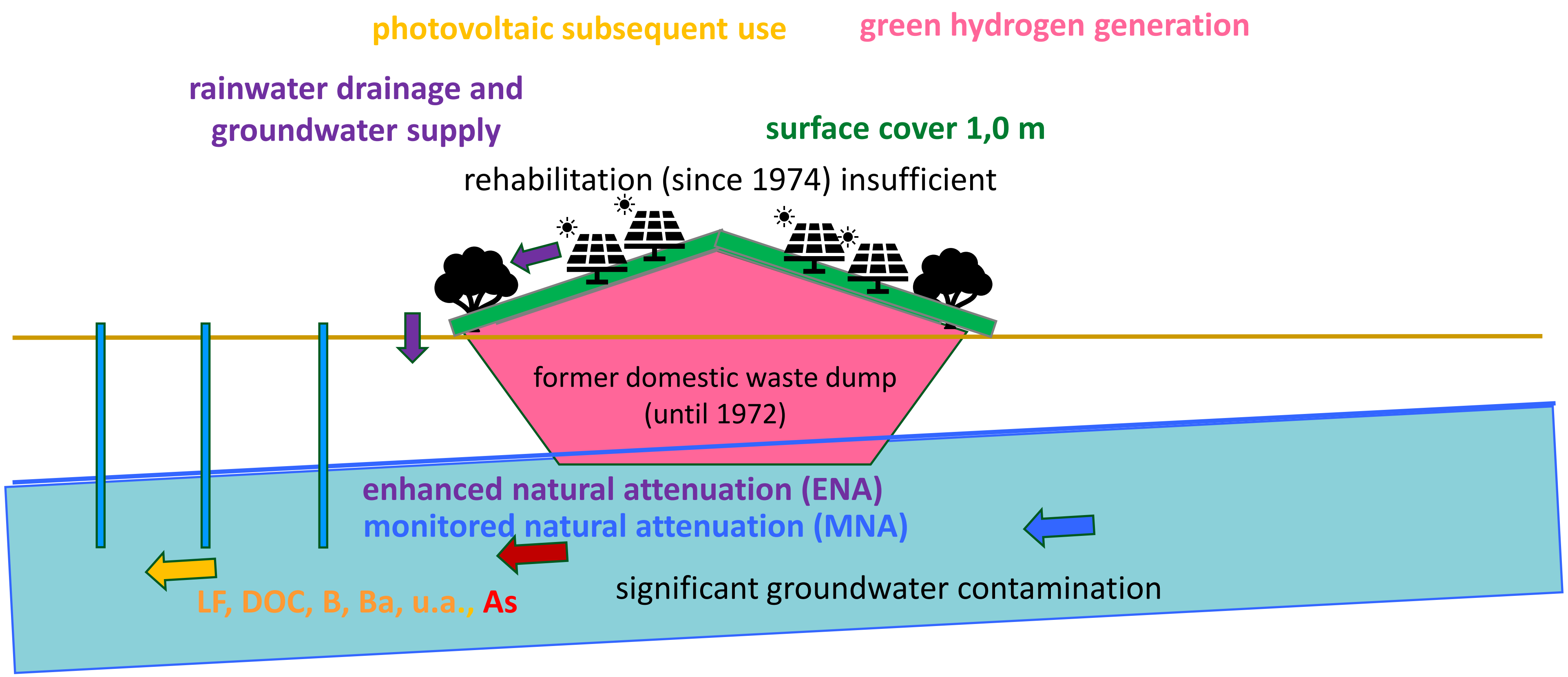
1. Landfill: recultivation under holistic approach (integrative) and from the perspective of proportionality (50 a)
2. Ground water: MNA-potencial under favorable site conditions
3. Subsequent use (60.000 m²): regenerative energy („old loads– new energies“)
4. Potencial ground water: enhancement of MNA processes (ENA)
5. Potencial photovoltaics: green hydrogen (operator)

Networking of ground water and landfill remediation with subsequent energy use as an innovative concept for minimizing climate-damaging $CO_2$ emissions



Well-planned solar farms contribute to the preservation and enhancement of biodiversity through a nature-friendly design

## Results and outlook



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