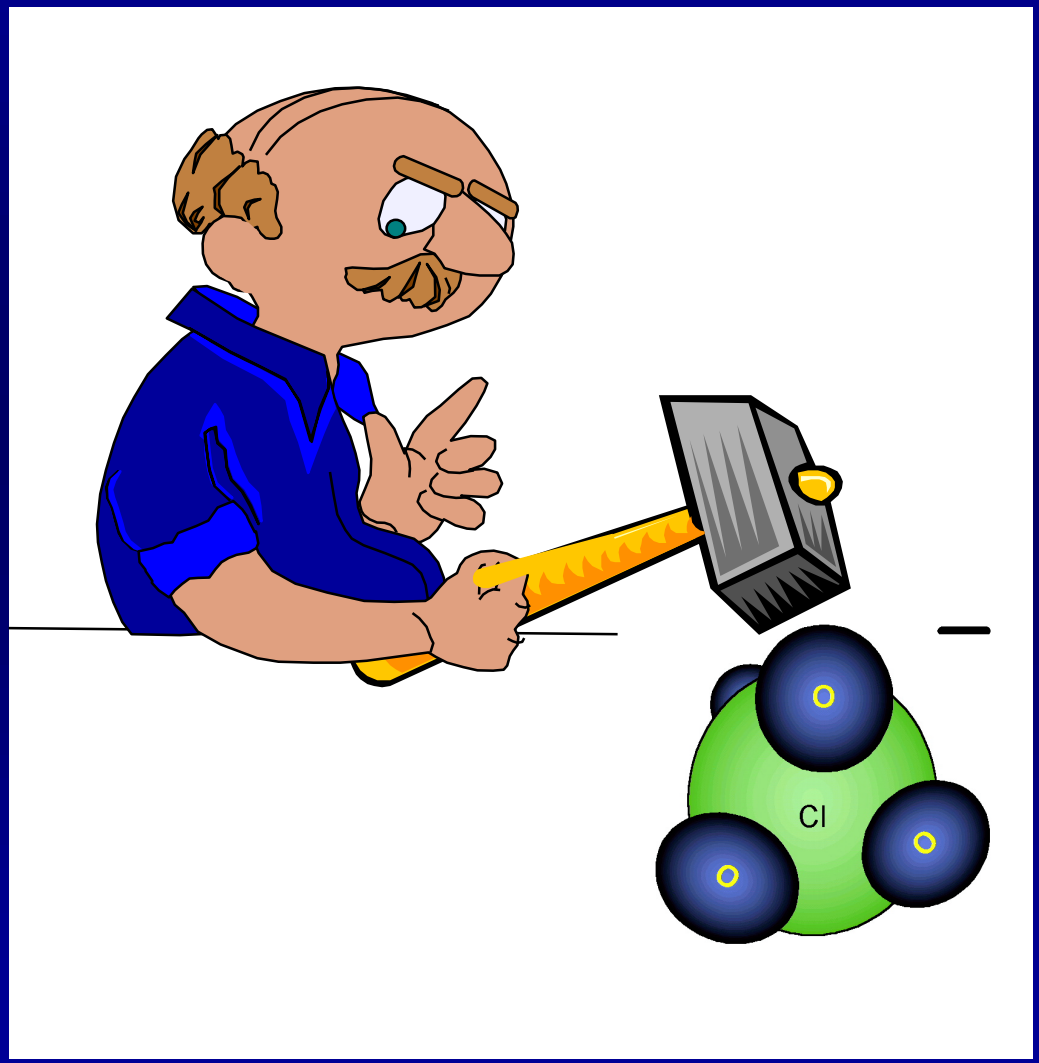
Perchlorate Treatment Technologies



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Agenda

- *Introduction*
- *Perchlorate chemistry*
- *Perchlorate treatment technologies (overview)*
- *Technology applicability*
- *Technology advantages/disadvantages*
- *In-situ Bioremediation*

Perchlorate Chemistry

- *Highest Oxidized Form of Chlorine - ClO_4^-*
- *Redox Paradox:*
  - *Strong Oxidizer, but not very reactive in groundwater*
  - *High Activation Energy Required*
- *Bad News: Abiotic Reduction Only Under Extreme Conditions*
- *Good News: Can Be Readily Reduced Biologically*

Perchlorate Treatment Technologies

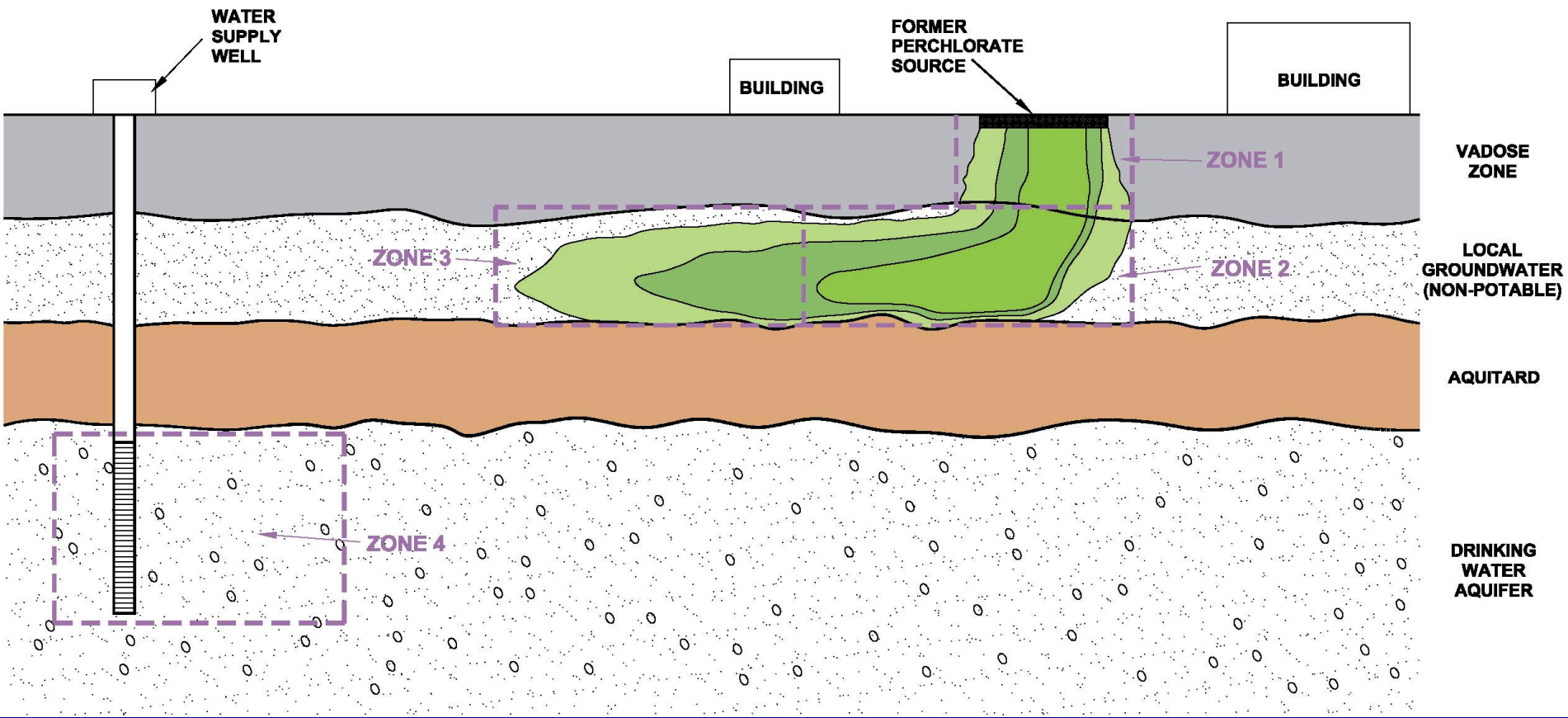
Ex-Situ

- *Ion Exchange*
- *(Fluidized Bed) Bioreactor*
- *Membrane Technologies (e.g. Reverse Osmosis)*

In-Situ

- *Enhanced Biological Reduction*
- *Monitored Natural Attenuation*
- *Soil Flushing*

Hypothetical Site Model



Treatment Technology Applicability

Impact Zone	Description	Typical Technologies/Options
Zone 1	*Vadose Zone (Soils)*	- *Excavation and Treatment/Disposal* - *In-situ Bioremediation* - *Soil Flushing*
Zone 2	*Groundwater with High [ClO_4]*	- *In-situ Bioremediation* - *Pump and Treat/Flush* - *Hydraulic Containment* - *Natural Attenuation*
Zone 3	*Groundwater with Low [ClO_4]*	- *In-situ Biobarrier* - *Hydraulic Containment* - *Natural Attenualtion*
Zone 4	*Impacted Potable Supply Well*	- *Wellhead Treatment* - *Blending (Low Impacts Only)* - *Shut Down*

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Ex-situ Ion Exchange Treatment

Advantages	Disadvantages
• *Full-scale operations in LA Area*	• *Perchlorate removed but not destroyed*
• *System can remove perchlorate to <2.5µgl or possibly lower*	• *Other large anions (sulfate, nitrates) are removed and need to be addressed further.*
• *Operation is fully automatic*	
• *Nitrates and nitrites present in the groundwater are removed simultaneously*	• *Resin to be disposed or regenerated*
• *Does not add TSS and TOC*	• *Full-scale application of catalytic destruction unit is unproven*

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Ex-situ Biological Treatment

Advantages

- *Can remove perchlorate to <4 µg/l*
- *Perchlorate is broken down into harmless compounds*
- *Nitrates and nitrites are degraded simultaneously*

Disadvantages

- *Regulatory/Community Concerns for potable use of discharge*
- *Potential upset due to toxic compounds*
- *Post treatment (filtration and disinfection), necessary for drinking water applications*
- *System is not packaged/large footprint*
- *High operator attention required*
- *Discharge may contain TOC*
- *Cold weather can reduce efficiency*
- *Reduction of sulfates may generate hydrogen sulfide (H_2S).*

In-Situ Biological Treatment of Perchlorate

Advantages

- *Eliminates need for (large) abovegrade treatment plant*
- *Demonstrated at several sites to treat perchlorate*
- *May improve secondary water quality (reducing nitrates and nitrites)*
- *Moderate capital cost*
- *Moderate operating costs*
- *Perchlorate is completely broken down into harmless compounds*

Disadvantages

- *May require dense extraction/ injection well field*
- *No long-term full-scale application data*
- *Possible mobilization of metals (iron and manganese)*
- *Possible sulfide formation*
- *Capital cost highly sensitive to hydrogeology*
- *Possible need for periodic rehabilitation of injection wells*
- *Potential upset by compounds that are toxic to bacteria*

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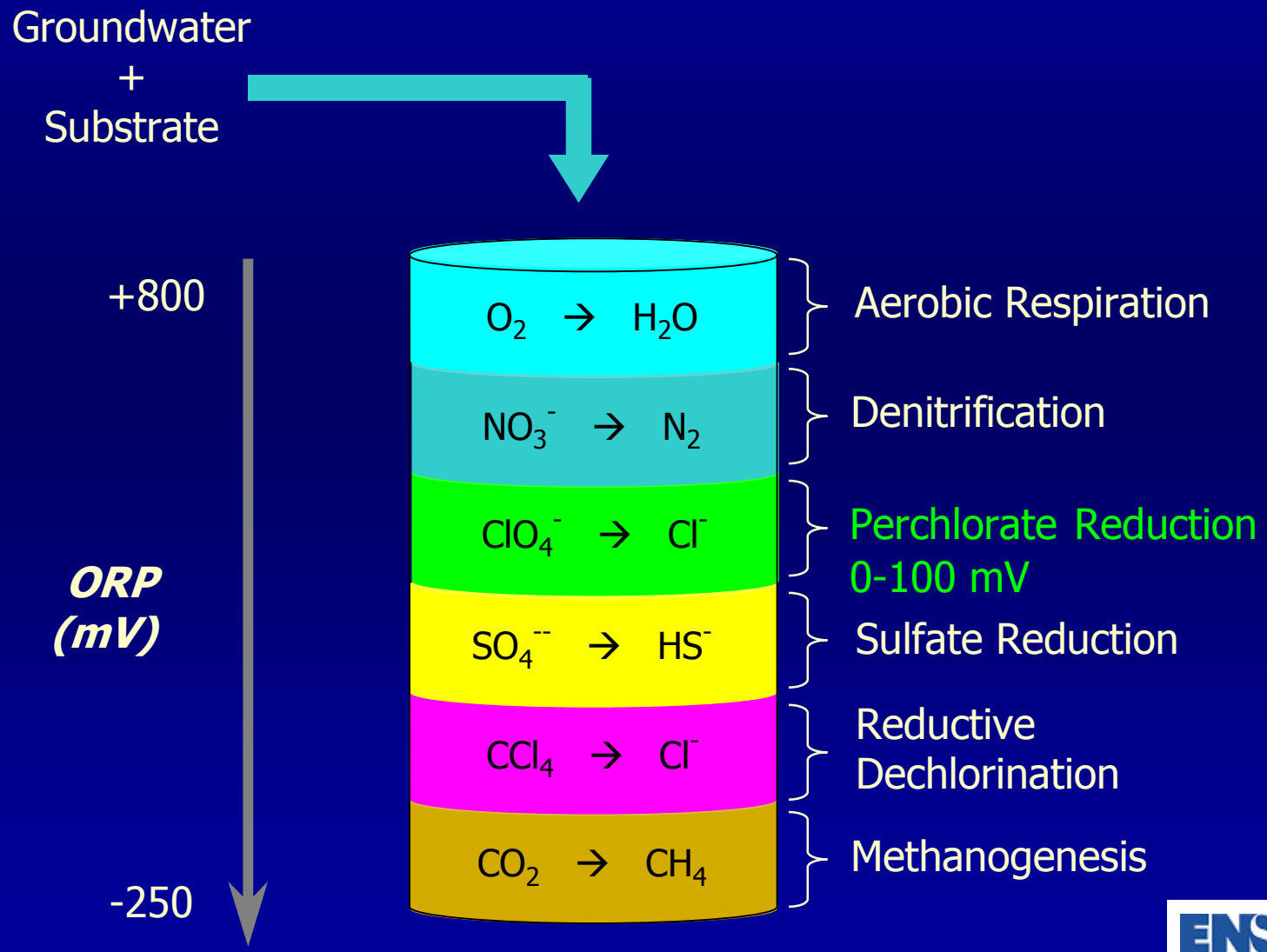
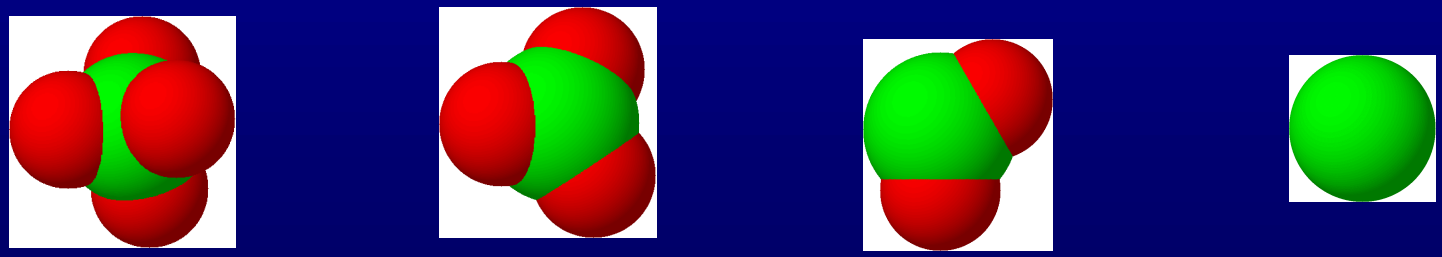
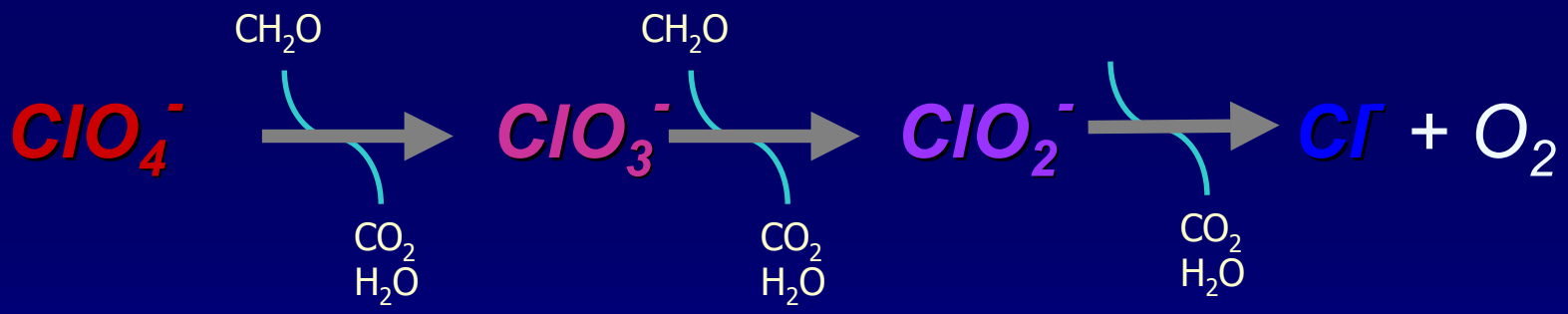
Degradation Processes Redox Potential



Perchlorate Reduction Pathway





Perchlorate **Chlorate** **Chlorite** **Chloride**

Oxidation State: (+7) (+5) (+3) (-1)

In-situ Bioremediation Analytes

Primary Analytes	Reason for Analysis
Total Dissolved Oxygen	*DO affects electron donor demand O_2*
pH	*6.5-7.5*
ORP	*0-100 mV range*
Total Organic Carbon	*May serve as electron donor*
Nitrate + Nitrite $NO_3^- + NO_2^-$	*Nitrate and nitrite affect electron donor demand*
Chlorate (ClO_3^-)	*Degradation product*
Chlorite (CLO_2^-)	*Degradation product*
Chloride Cl^-	*Degradation product may be masked by high background (Cl^-)*

Important Variables

- *Stratigraphy*
- *Hydraulic Conductivity*
- *Storativity*
- *Groundwater Flow and Transport*
- *Perchlorate Distribution*
- *General Minerals Analysis*

In-situ Bioremediation of Perchlorate

- *In-situ bioremediation of perchlorate is an emerging technology*
- *Laboratory-scale studies, R&D*
  - *Penn State University, Southern Illinois University, Envirogen, GeoSyntec*
- *Field Demonstrations*
  - *Aerojet Superfund Site (CA)*
  - *Edwards AFB (CA)*
- *Biobarrier (immobile C source)*
  - *NWIRP (McGregor, TX)*

Ex-situ Bioremediation of Perchlorate

- *Ex-situ Bioremediation of perchlorate is a proven technology:*
  - *Aerojet (N. CA)*
    - *4 full-scale bioreactors operating since 1998*
    - *2,500 µg/L consistently reduced to <4 µg/L*
  - *San Gabriel Superfund Site (CA)*
  - *Tyndall AFB (FL)*
  - *Thiokol (UT)*
  - *Longhorn Ammunition Plant (TX)*
  - *NWIRP (McGregor, TX)*

Technology Status of In-Situ Bioremediation of Perchlorate

- *Numerous potentially suitable electron donors (compost, mulch, vegetable oil, sugars, alcohols, lactate, acetate, etc.)*
- *Implementable through recirculation cells or in biobarriers*
- *Few in-situ field applications have been completed, but numerous studies are underway*
- *Will require site-specific treatability testing and pilot-scale field demonstration*