# Sustainable, Decentralized Approaches to Water Use (Biological Approaches)

Jay L. Garland
Dynamac Corporation
Mail Code DYN-3, Kennedy Space Center, Florida 32899
(321)861-3503
jay.l.garland@nasa.gov

“I believe we can accomplish great and profitable things within a new conceptual framework—one that values our legacy, honors diversity, and feeds ecosystems and societies . . . It is time for designs that are creative, abundant, prosperous, and intelligent from the start.”

William McDonough

- **Biotechnology**: the manipulation (as through genetic engineering) of living organisms or their components to produce useful usually commercial products (as pest resistant crops, new bacterial strains, or novel pharmaceuticals); *also* **:** any of various applications of biological science used in such manipulation

- ***Ecological design:*** *any form of design that minimizes environmentally destructive impacts by integrating itself with living processes.' This integration implies that the design respects species diversity, minimizes resource depletion, preserves nutrient and water cycles, maintains habitat quality, and attends to all the other preconditions of human and ecosystem health.*
  *—from Ecological Design by Sim Van Der Ryn and Stuart Cowan*

# Overall Design Elements

- Separation for optimization
- Integrated biological and physical/chemical systems offer the greatest potential for sustainable approaches for base camp applications
- Biological components require start-up time
  - Depends on process (organic degradation vs. N removal)

# Residential Water Use

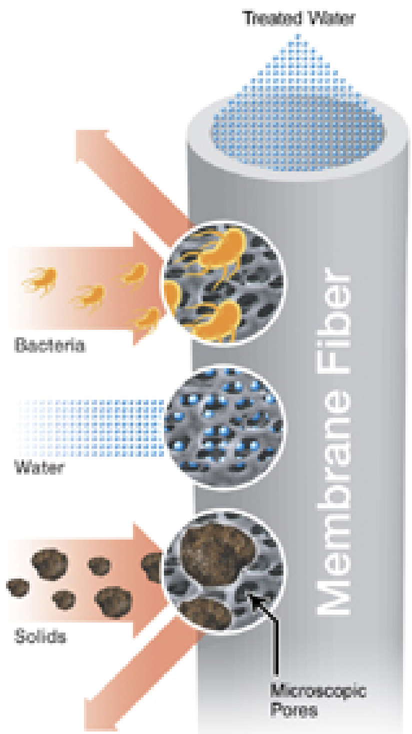
- American Water Works Association
  - Study of 1188 homes in 14 North American Cites (1996-98)
  - 146,000 gallons (over 500,000 liters) per household annually
    - 58% outdoors
    - 42% indoors
  - Of indoor use:
  - Homes without water efficient fixtures
    - Toilets 20.1 gallons person$^{-1}$ day$^{-1}$ (34%)
    - Clotheswasher 15 gallons person$^{-1}$ day$^{-1}$ (25%)
    - Shower 13.3 gallons person$^{-1}$ day$^{-1}$ (22%)
    - Faucets gallons 10.9 person$^{-1}$ day$^{-1}$ (15%)
  - Homes with water efficient fixtures
    - Clotheswasher 15 gallons person$^{-1}$ day$^{-1}$ (33%)
    - Faucets 10.9 gallons person$^{-1}$ day$^{-1}$ (24%)
    - Showers 10 gallons person$^{-1}$ day$^{-1}$ (22%)
    - Toilets 9.6 gallons person$^{-1}$ day$^{-1}$ (21%)

# Wastestream Characteristics

- Gray water
  - largest mass, most dilute, low levels of microbial contamination
  - easiest to treat and reuse
- Urine
  - Vast majority of the inorganic nutrients, little organic or microbial contamination, trace levels of “emerging” contaminants
  - requires more specialized treatment for nutrient removal, can be linked to biomass production
- Black water
  - relatively little inorganic nutrient content, high levels of organics and microbes
  - Probably best treated as a solid waste stream (minimize dilution or mixing with nutrients)

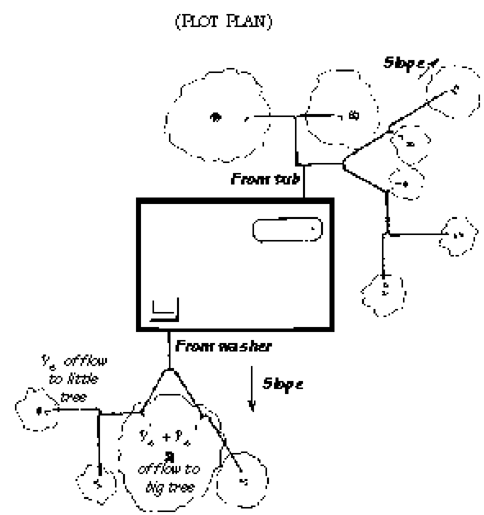
# Alternative Strategies For Separate Onsite Graywater Treatment

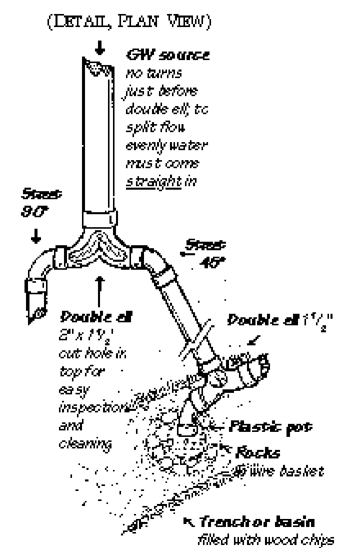
## Treatment & Reuse




Membrane Bioreactors widely applied for GW recycling in Japan

## Direct Application to Landscape




Increasingly used by homeowners
WERF funded long term monitoring study

# Direct Graywater Processing Scheme

Transpiration

Condensate

Graywater addition as
liquid level replenishment

Surfactant Degradation
in the Rhizosphere

Maintenance of water quality

# Green Roof Water Recycling System (Grow)
# www.wwuk.co.uk

Household Scale Unit

Multi-Story Housing Unit (4m x 2m x 1m)

Graywater is pumped through system from storage  tank(17 h hydraulic retention time)

“Aquatic” plants selected for hardiness, dendritic roots, low maintenance, high aesthetic
*Iris pseudocorus, Juncus effuses, Mentha aquatica*

125 L $m^{-2}$ processing capacity

Processed water treated with ultraviolet light, dyed green   “green water”

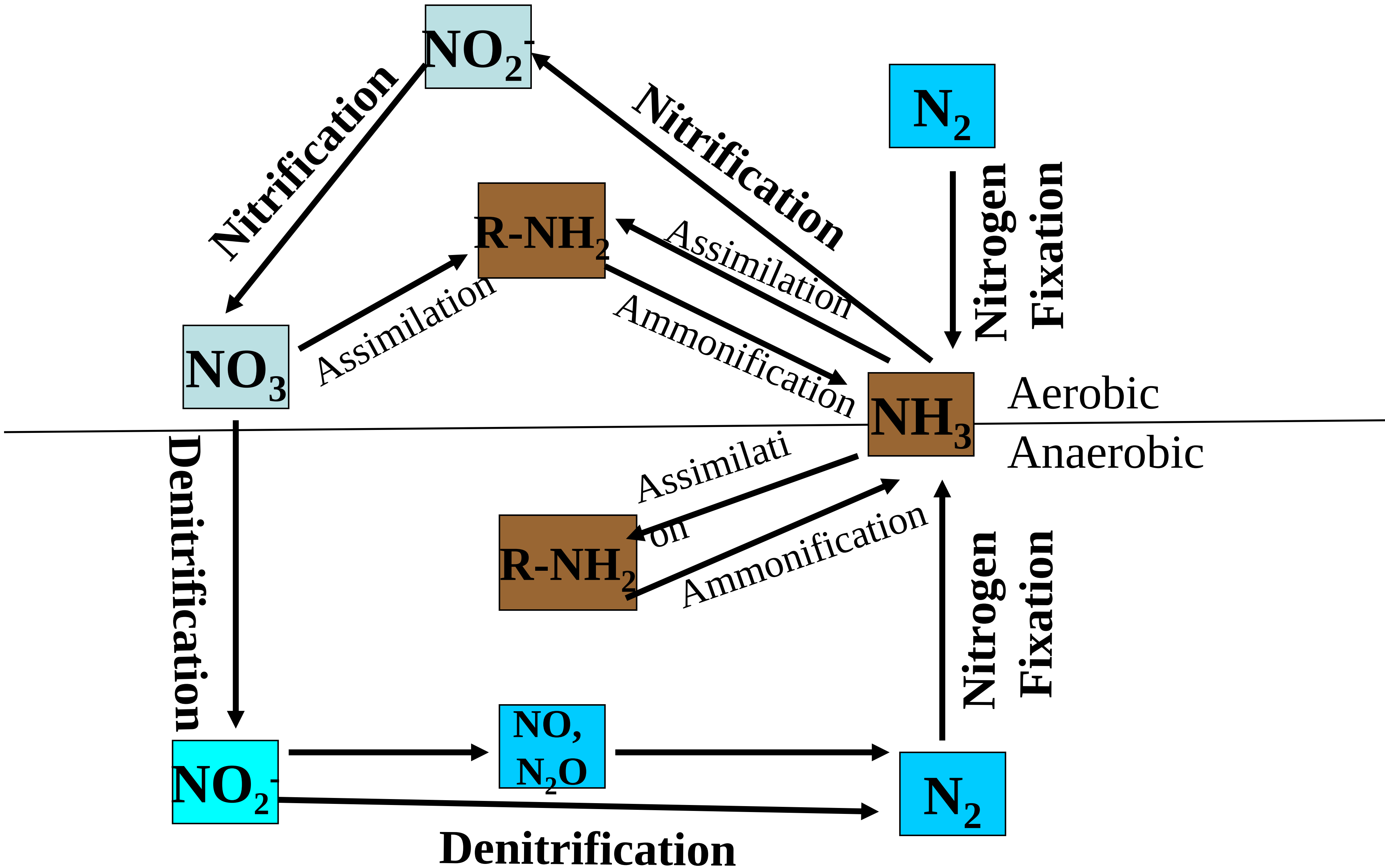
# Types of Green Roof

## International Green Roof Association (igra-world.com)

| | **Extensive Green Roof** | **Semi-Intensive Green Roof** | **Intensive Green Roof** |
|---|---|---|---|
| **Maintenance** | Low | Periodically | High |
| **Irrigation** | No | Periodically | Regularly |
| **Plant communities** | Moss-Sedum-Herbs and Grasses | Grass-Herbs and Shrubs | Lawn or Perennials, Shrubs and Trees |
| **System build-up height** | 60 - 200 mm | 120 - 250 mm | 150 - 400 mm on underground garages > 1000 mm |
| **Weight** | 60 - 150 kg/$m^2$<br>13 -30 lb/sqft | 120 - 200 kg/$m^2$<br>25 - 40 lb/sqft | 180 - 500 kg/$m^2$<br>35 - 100 lb/sqft |
| **Costs** | Low | Middle | High |
| **Use** | "Ecological protection layer" | "Designed Green Roof" | "Park like garden" |

# Urine Processing

- Assumes separate collection of most of the urine flow
- Microbiological treatment to remove nutrients (particularly N) and organics
  - Pretreatment to increase efficiency of P/C treatment to potable water
  - Typical N-removal process (nitrification-denitrification) is limited by low C/N ratio of the waste stream
    - Need alternative energy sources
- Direct use for photosynthetic production
  - Algal bioreactors for biodiesel production
  - Food production

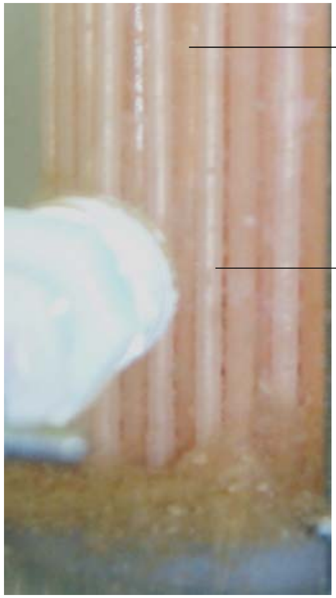


$NO_2^-$
Nitrification
Nitrification
$N_2$
R-$NH_2$
Assimilation
Nitrogen Fixation
$NO_3$
Assimilation
Ammonification
$NH_3$
Aerobic
Anaerobic
Assimilati
on
Denitrification
R-$NH_2$
Ammonification
Nitrogen Fixation
$NO_2^-$
NO, $N_2O$
$N_2$
Denitrification

# Advantages of Hollow Fiber Membrane Biofilm Reactors

- Efficient delivery of gases
  - Diffusion rather than sparging
    - >50% of the operating costs of typical sewage treatment facilities is associated with air delivery
  - Complete utilization of gas in the attached biofilm
- Safe delivery of gases
  - Since most gases are relatively insoluble, sparging leads to gas accumulation in reactor headspaces
  - Limits the use of explosive gases (i.e., $H_2$ and $CH_4$), particularly in combination with $O_2$
  - Delivery of gases to the biofilm via diffusion eliminates this problem

# Redox Control Reactor – Concept and Initial Demonstration



**Aerobic Processes ($O_2$ diffusion)**

Nitrification

$2NH_4^+ + 3O_2 \rightarrow 2H_20 + 4H^+ + 2N0_2^-$

$2NO_2- + O_2 \rightarrow 2NO_3^-$

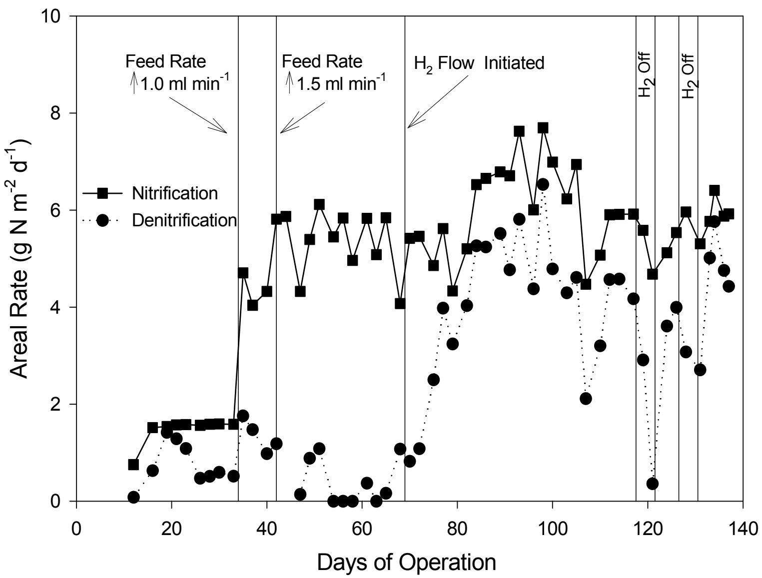
**Hydrogenotrophic Processes ($H_2$ diffusion)**

Denitrification

$2NO_2- + 2H^+ + 3H_2 \rightarrow N_2 + 4H_20$

$NO3- +H2 \rightarrow NO_2^- + H_20$

Simultaneous processes to purify $NH_4$-rich wastewater



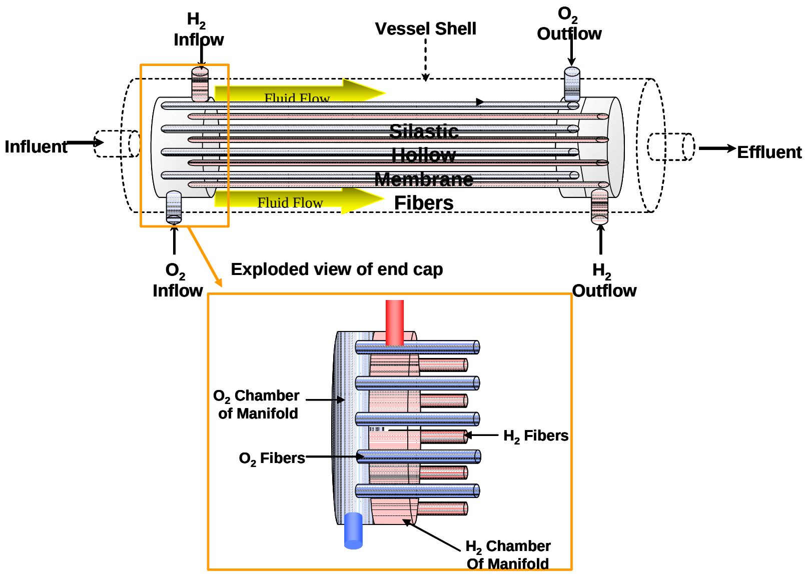




***Figure 5.*** *Detailed Schematic of Redox Reactor*

# Future Critical R&TD Needs

- Rapidly deployable, modular processing units
  - Integrated biological and physical/chemical treatment units
  - Separate systems for graywater vs “blackwater

- Should strongly consider separate “yellow” and “black” water treatment approaches
  - Yellow water for water regeneration and/or as feed for photobioreactors for energy production
  - Black “water” as part of the solid waste to energy process

- While further, basic R&TD needed for individuals components, integrated real-world testing is a priority
  - Microbiological and chemical
  - Long term operation under variables loads
    - biomass management issues, resistance/resiliency