Using Aquaponics to Immerse Students

in Science, Technology, Engineering, and Math

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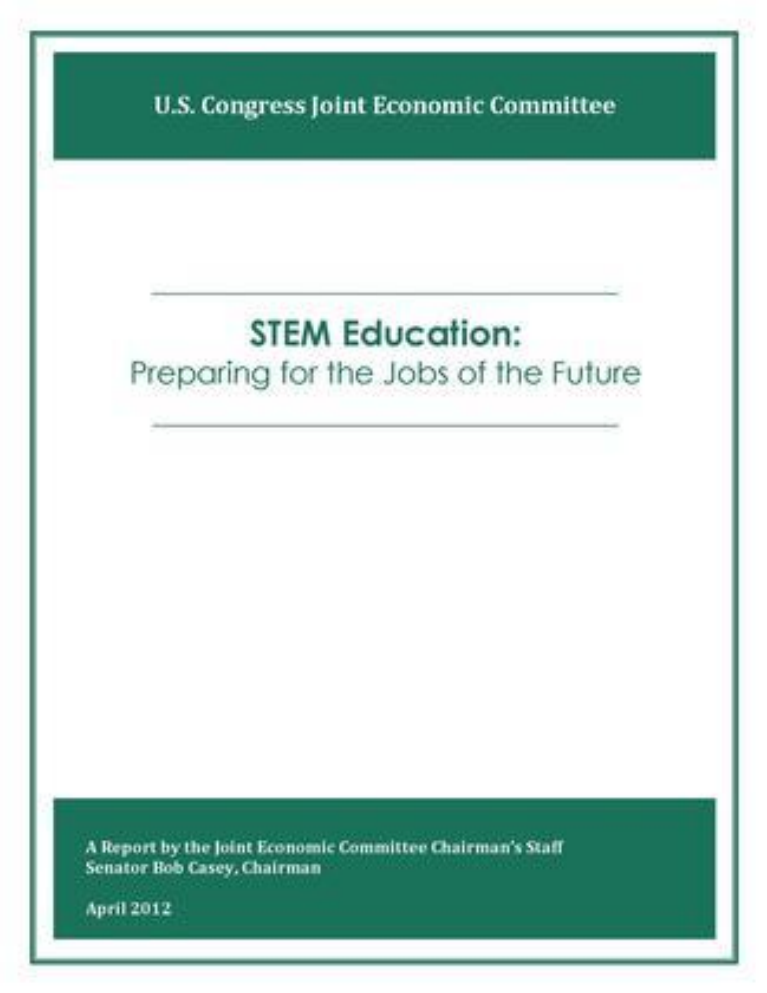
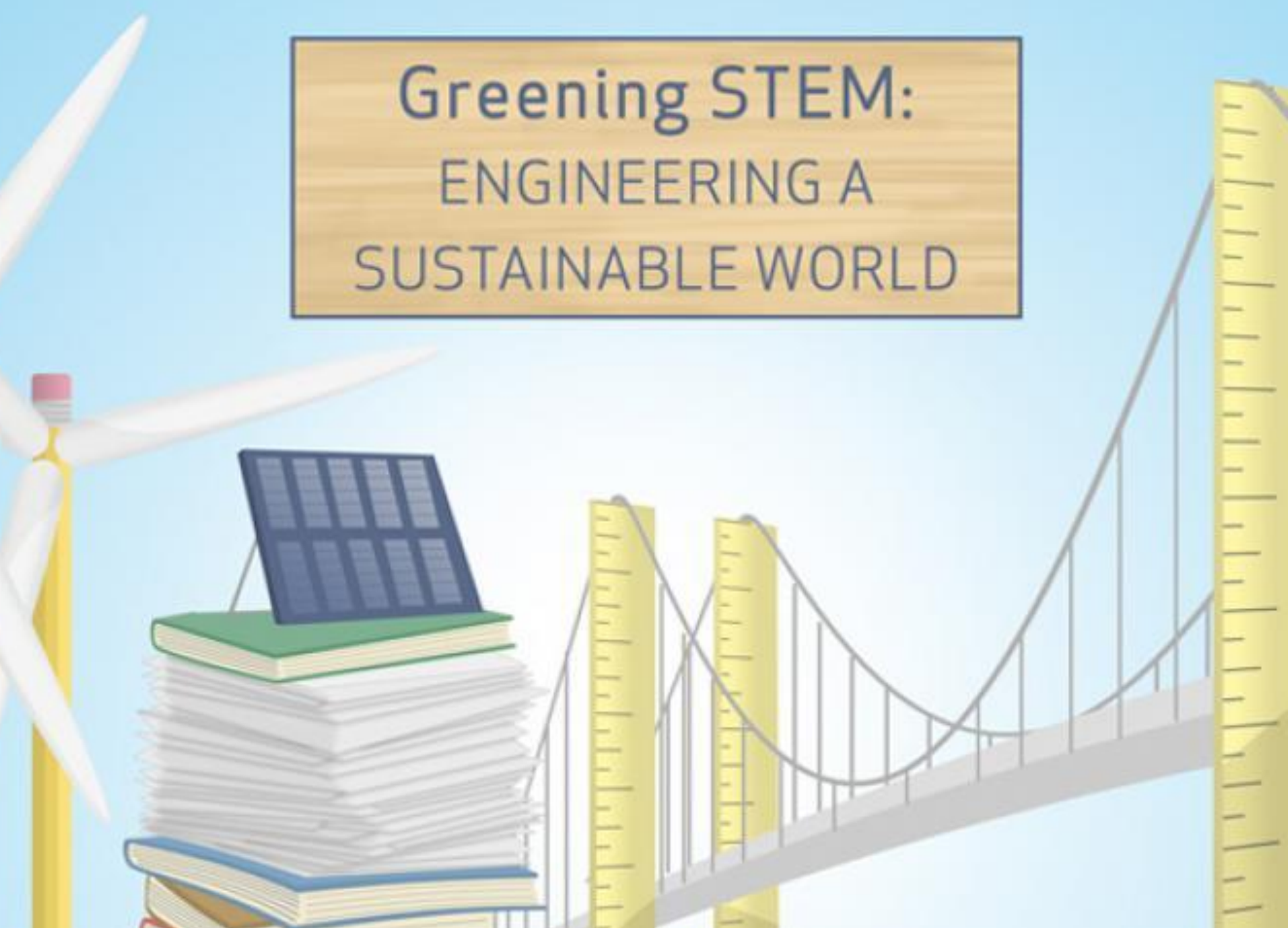
St. Louis Community College

Conceptual Framework

What We Need & Why



Greening STEM:
ENGINEERING A SUSTAINABLE WORLD



The US & Other Nations

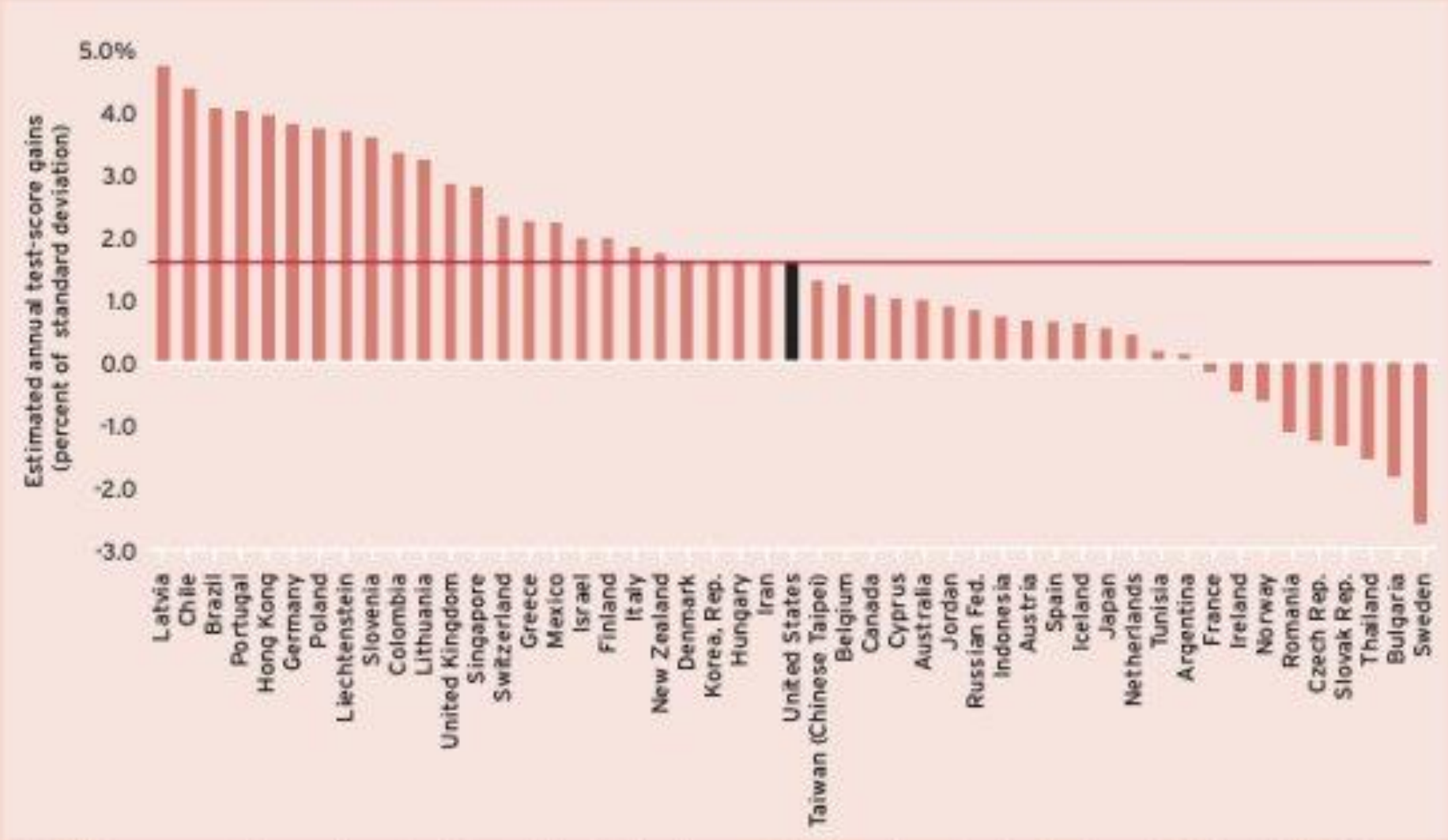
Where We Are

How Does the U.S. Compare in STEM Education?

- US is 52nd in the quality of mathematics and science education
- 5th (and declining) in overall global competitiveness
- US ranks 27th in developed nations in the proportion of college students receiving undergraduate degrees in science or engineering
- There are more foreign students studying in U.S. graduate schools than the number of U.S. students
- Over 2/3 of the engineers who receive Ph.D.'s from United States universities are not United States citizens

Barely Keeping Pace (Figure 1)

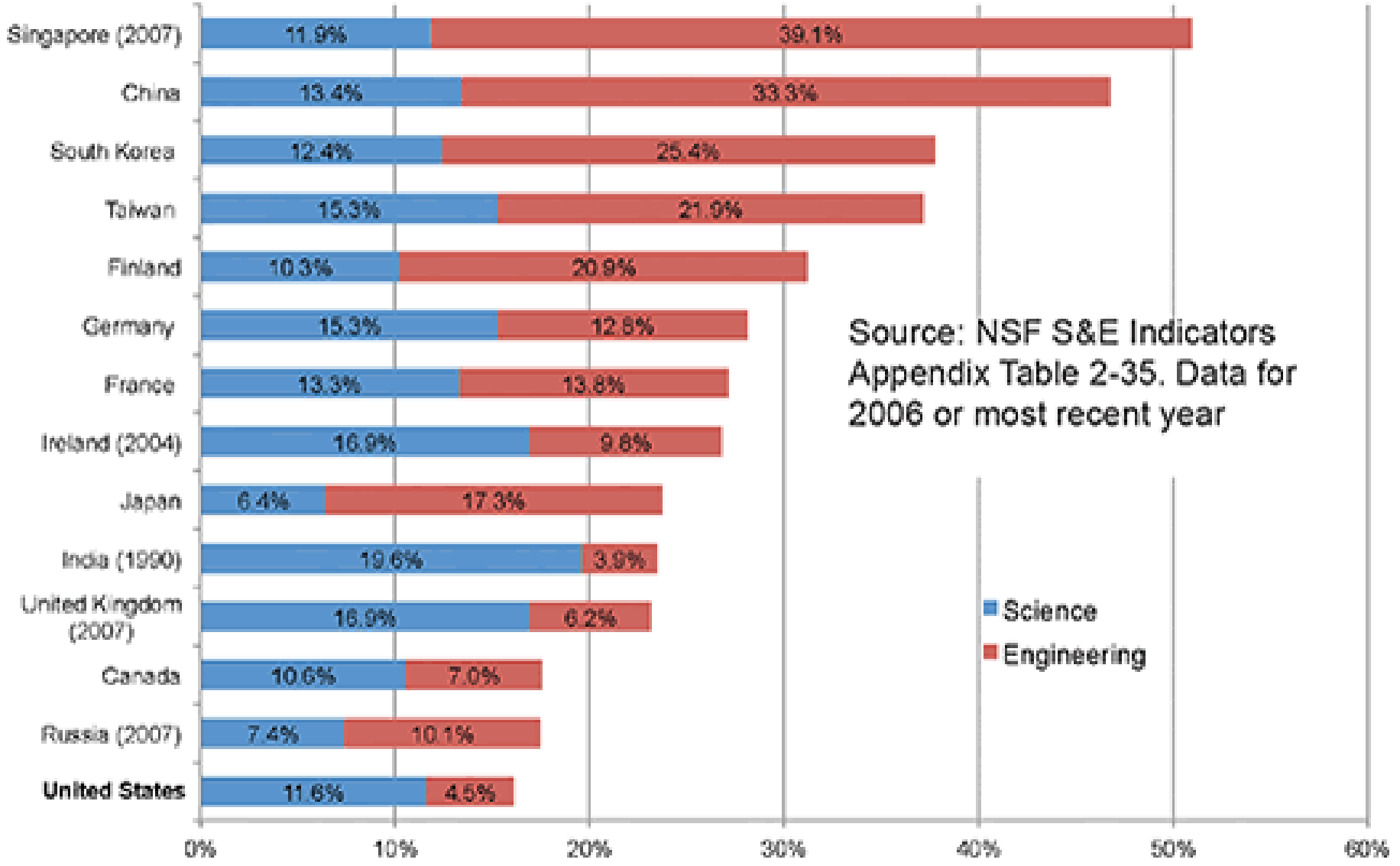
U.S. rate of improvement is in the middle of the pack.



NOTE: The bars represent the overall annual rate of growth in student achievement in math, reading, and science in 49 countries, from 1995 to 2009.

SOURCE: Authors' calculations based on National Assessment of Educational Progress. See methodology sidebar for detailed explanation.

Percentage of undergraduates receiving undergraduate degrees in the natural sciences and engineering in selected nations



So Let's Interest Students To Pursue STEM Education!

The Role of Aquaponics

Career Potentials

In STEM

STEM Job Growth

AS PROJECTED BY U.S. DEPT. OF LABOR **2012-22**

18%

COMPUTER & MATHEMATICAL

ARCHITECTURAL & ENGINEERING

26%

MATHEMATICAL & SCIENCE

LIFE, PHYSICAL, SOCIAL SCIENCE

7.3%

10%

STEM CAREERS:

DEMAND IS UP FOR TODAY'S INNOVATORS

STEM (SCIENCE TECHNOLOGY ENGINEERING MATHEMATICS)

Faster aircraft, bolder video games, better medicines—technology moves forward every day. And STEM-savvy workers make those advances happen. Without the work of scientists, technicians, engineers, mathematicians, and other skilled workers, most new products and discoveries would never be developed. The growing demand across all industries for new products and innovations is fueling the demand for STEM talent in the U.S. and abroad. There are many reasons to consider a STEM career. Beyond the premium wages and increasing opportunities, STEM workers are today's innovators and inventors. They often work for the most progressive companies generating new ideas, inventing new products and solving complex business and societal problems. Their contributions are great and their impact vast – creating downstream jobs and fueling economic growth.

TOP 11 STEM OPPORTUNITY MARKETS

The top 11 metropolitan areas have a strong concentration and a sizeable volume of STEM jobs (compared to total employment) and are predicted to grow their STEM employment by more than 6% in the next five years.

ANNUAL INCOME

STEM AVERAGE $77,880

U.S. AVERAGE $43,460

THE HIGHEST PAYING STEM OCCUPATIONS ($100K+) ARE:

- Natural Science Managers
- Engineering Managers
- Computer/Info Systems Managers
- Petroleum Engineers

HIGHEST SHARE OF SCIENCE AND TECHNOLOGY PROFESSIONALS (AS A % OF EMPLOYMENT)

1. Luxembourg
2. Sweden
3. Denmark
4. Switzerland
5. Norway

12. The U.S.

STEM WORKERS ARE TURNING TO FREE AGENCY

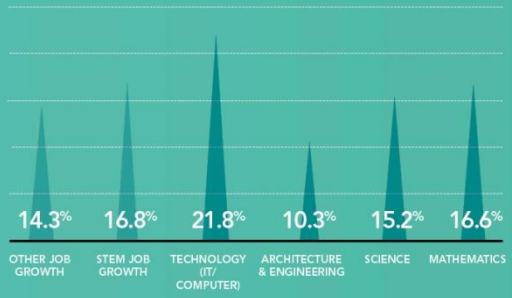
Between 2009 – 2011, the growth of self-employed STEM workers in the U.S. was nearly twice the rate of growth for all self-employed workers

STEM PROFESSIONALS WITH A BACHELOR DEGREE OR HIGHER

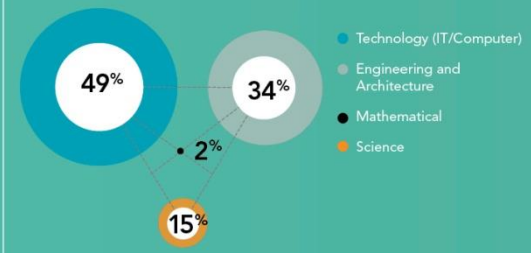
68%

While there are some STEM opportunities for those with a high school diploma, the majority of new and replacement jobs in STEM will require at least some postsecondary education.

DEMAND FOR STEM PROFESSIONALS 2010-2020



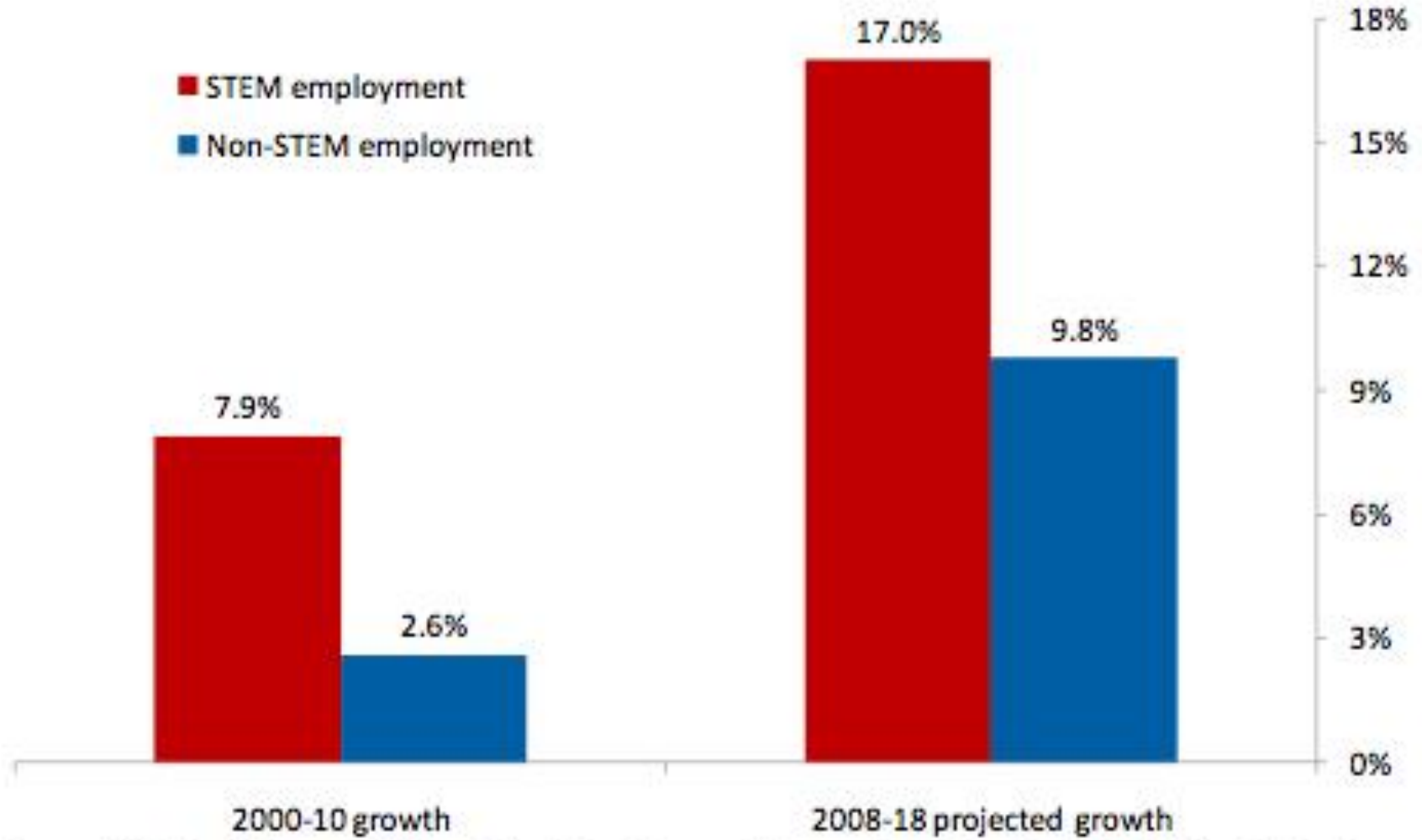
THE STEM OCCUPATIONAL BREAKDOWN



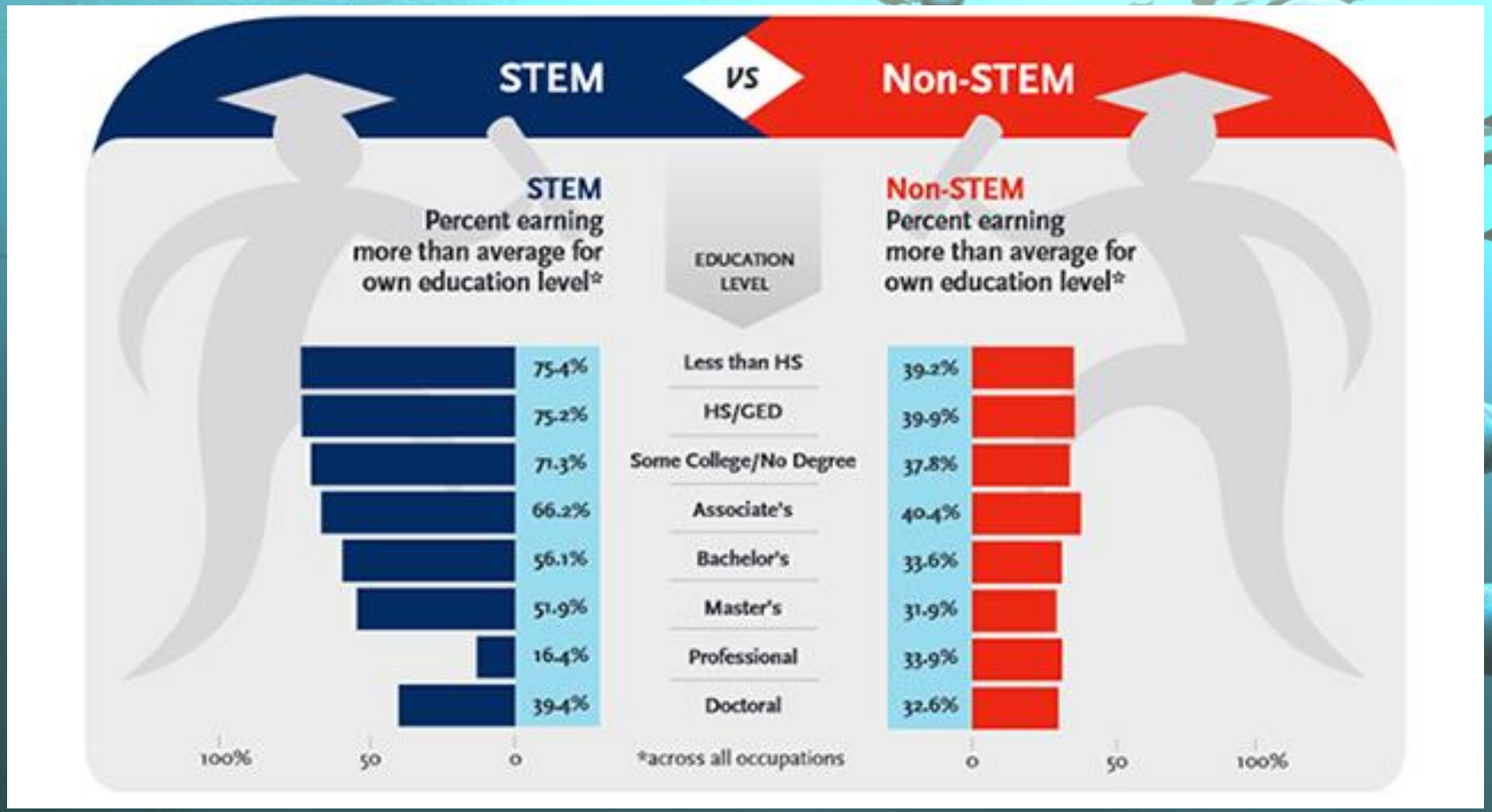
THE TOP 8 STEM JOBS (% GROWTH THROUGH 2020)

KELLY

Figure 1. Recent and Projected Growth in STEM and Non-STEM Employment



Source: ESA calculations using Current Population Survey public-use microdata and estimates from the Employment Projections Program of the Bureau of Labor Statistics.


STEM
VS
Non-STEM
STEM
Percent earning more than average for own education level*
EDUCATION LEVEL
Non-STEM
Percent earning more than average for own education level*
Less than HS
75.4%
39.2%
HS/GED
75.2%
39.9%
Some College/No Degree
71.3%
37.8%
Associate's
66.2%
40.4%
Bachelor's
56.1%
33.6%
Master's
51.9%
31.9%
Professional
16.4%
33.9%
Doctoral
39.4%
32.6%
100%
50
0
*across all occupations
0
50
100%

FOCUS

Best Jobs in America

1 **Systems Engineer**
Information Technology (88,000)
$87,100 | **$130,000**

2 **Physician Assistant**
Healthcare (82,000)
$90,900 | **$124,000**

3 **College Professor**
Education (278,000)
$70,400 | **$115,000**

4 **Nurse Practitioner**
Healthcare (23,000)
$85,200 | **$113,000**

5 **IT Project Manager**
IT (174,000)
$98,700 | **$140,000**

6 **Certified Public Accountant**
Financial (189,000)
$74,200 | **$138,000**

7 **Physical Therapist**
Healthcare (181,000)
$74,300 | **$98,100**

8 **Computer/Network Security Consultant**
IT (13,000)
$99,700 | **$152,000**

9 **Intelligence Analyst**
Government (51,000)
$82,500 | **$115,000**

10 **Sales Director**
Sales and Marketing (97,000)
$140,000 | **$239,000**

11 **Anesthesiologist**
Healthcare (23,000)
$292,000 | **$408,000**

12 **Software Developer**
IT (796,000)
$79,400 | **$116,000**

13 **Pharmacist**
Healthcare (198,000)
$109,000 | **$134,000**

14 **Occupational Therapist**
Healthcare (107,000)
$69,700 | **$100,000**

15 **Nurse Anesthetist**
Healthcare (19,000)
$157,000 | **$214,000**

16 **Software Product Manager**
IT (37,000)
$106,000 | **$148,000**

17 **Business Analyst, IT**
IT (125,000)
$82,600 | **$119,000**

18 **Attorney/Lawyer**
Legal (541,000)
$115,000 | **$262,000**

19 **Physician/General Practice**
Healthcare (90,000)
$150,000 | **$228,000**

20 **Human Resources Manager**
Other (226,000)
$71,800 | **$111,000**

21 **Senior Financial Analyst**
Financial (127,000)
$79,900 | **$109,000**

22 **Physician/Obstetrician/Gynecologist**
Healthcare (14,000)
$222,000 | **$338,000**

23 **Clinical Psychologist**
Healthcare (57,000)
$81,100 | **$172,000**

24 **Psychiatrist**
Healthcare (20,000)
$177,000 | **$279,000**

25 **Veterinarian**
Other (68,000)
$83,900 | **$157,000**

30 **Telecommunications Network Engineer**
IT (21,000)
$86,200 | **$130,000**

33 **Securities Trader**
Financial (17,000)
$113,000 | **$491,000**

35 **Education/Training Consultant**
Financial (23,000)
$77,800 | **$157,000**

Emergency Room Physician
Healthcare (22,000)
$249,000 | **$386,000**

Product Management Director
Sales and Marketing (17,000)
$145,000 | **$201,000**

Key

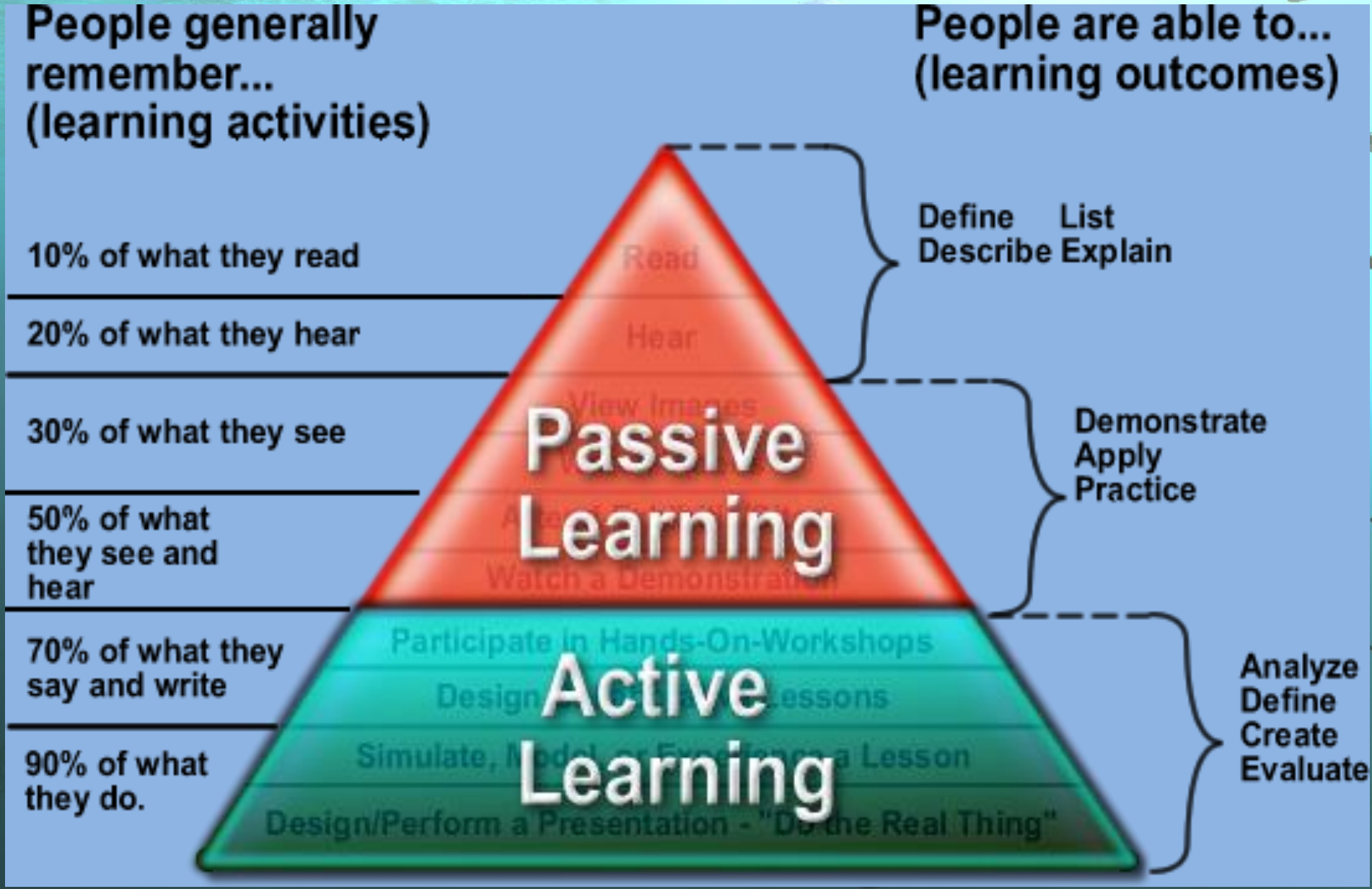
1 Top 50 Rank

Job Title
Sector (Total Jobs)
Median salary | **Top pay**

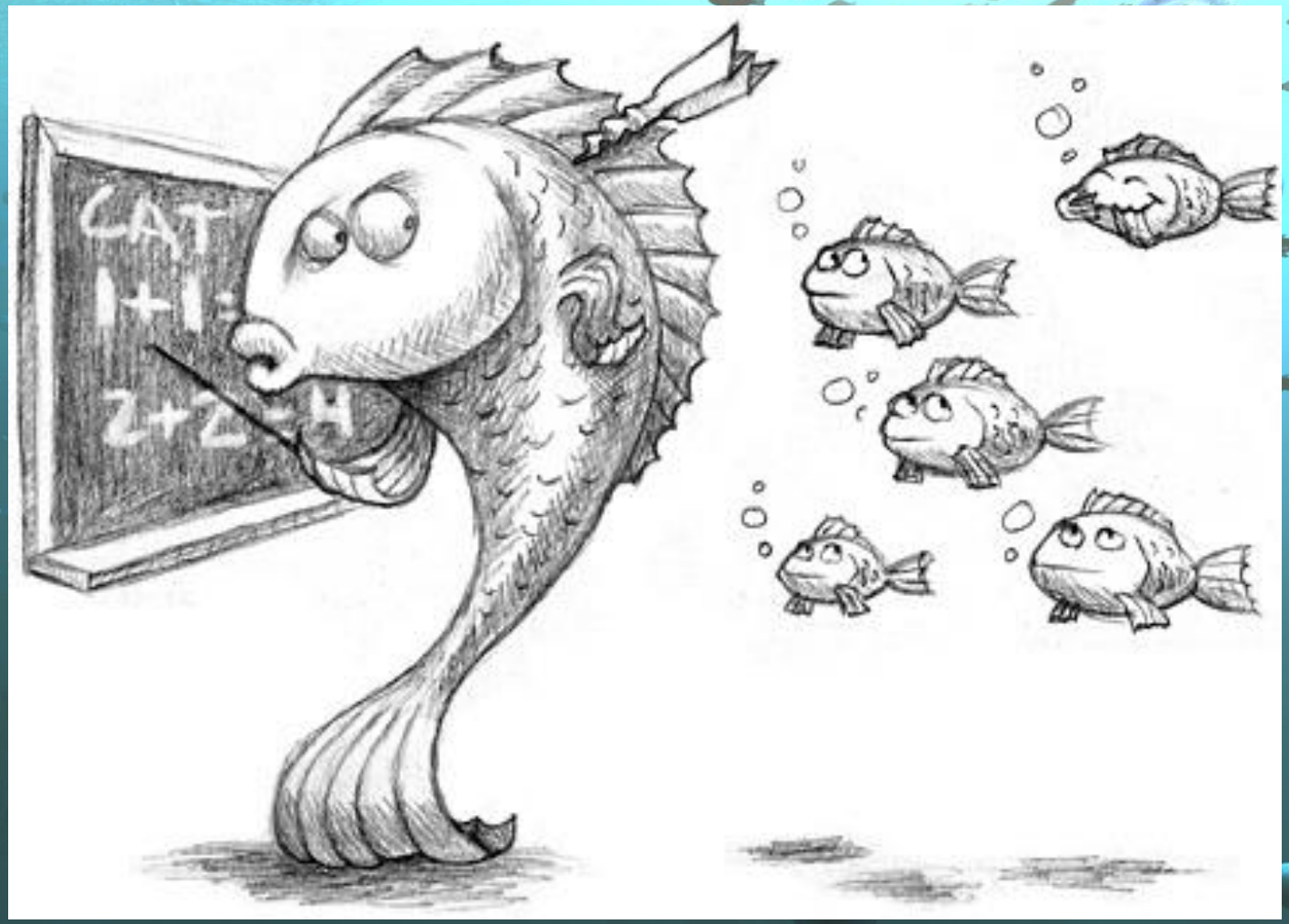
Selected interest areas
- highest paid Salary
- highest median Salary
- most flexibility
- most satisfaction
- benefit to society
- highest job growth
- highest low stress
- most security
- future growth

How Best to Learn?

And teach?


People generally remember... (learning activities)
People are able to... (learning outcomes)
10% of what they read
20% of what they hear
30% of what they see
50% of what they see and hear
70% of what they say and write
90% of what they do.
Read
Hear
Passive Learning
Participate in Hands-On-Workshops
Active Learning
Design/Perform a Presentation - "Do the Real Thing"
Define List
Describe Explain
Demonstrate
Apply
Practice
Analyze
Define
Create
Evaluate

Learning STEM via Immersion



Authentic, application oriented, experiential learning

The Aquaponics STEM Program at SLCC

Overview

- History of Hydroponics & Aquaponics
- Scientific Process
- ***Inquiry-based, Authentic Learning & Real-Life Relevancy STEM Learning Activities***
- Setting Up the System
- Fish Ecology
- Plant Ecology
- Ecosystem Ecology
  - Nutrient cycles & energy flow
  - Food webs and non-trophic interactions
- Experiments
- Presentations
- Measurement of Outcomes: Affective & Cognitive

Scientific Process I

- Research hydro- and aquaponics
- Build a system
- Research fish ecology
- Research plant ecology
- Research ecosystem dynamics

Scientific Process II

- Design research projects based on preliminary research
- Present research proposal for peer review

STEM Infused Throughout

- Option to prepare budget and propose different ponic system designs
- Motto- adopt & adapt!
- Grant process merit review

Food Banking & Donations

- **Social relevancy component**

Unaffected 4 Year Olds

Impaired 4 Year Olds

EFFECTS OF PESTICIDES ON CHILDREN

Environmental Working Group's

SHOPPER'S GUIDE TO PESTICIDES in PRODUCE

DIRTY DOZEN Buy These Organic	CLEANEST 12 Lowest in Pesticides
Peaches	Onions
Apples	Avocado
Sweet Bell Peppers	Sweet Corn (Frozen)
Celery	Pineapples
Nectarines	Mango
Strawberries	Asparagus
Cherries	Sweet Peas (Frozen)
Pears	Kiwi Fruit
Grapes (Imported)	Bananas
Spinach	Cabbage
Lettuce	Broccoli
Potatoes	Papaya

WORST — BEST

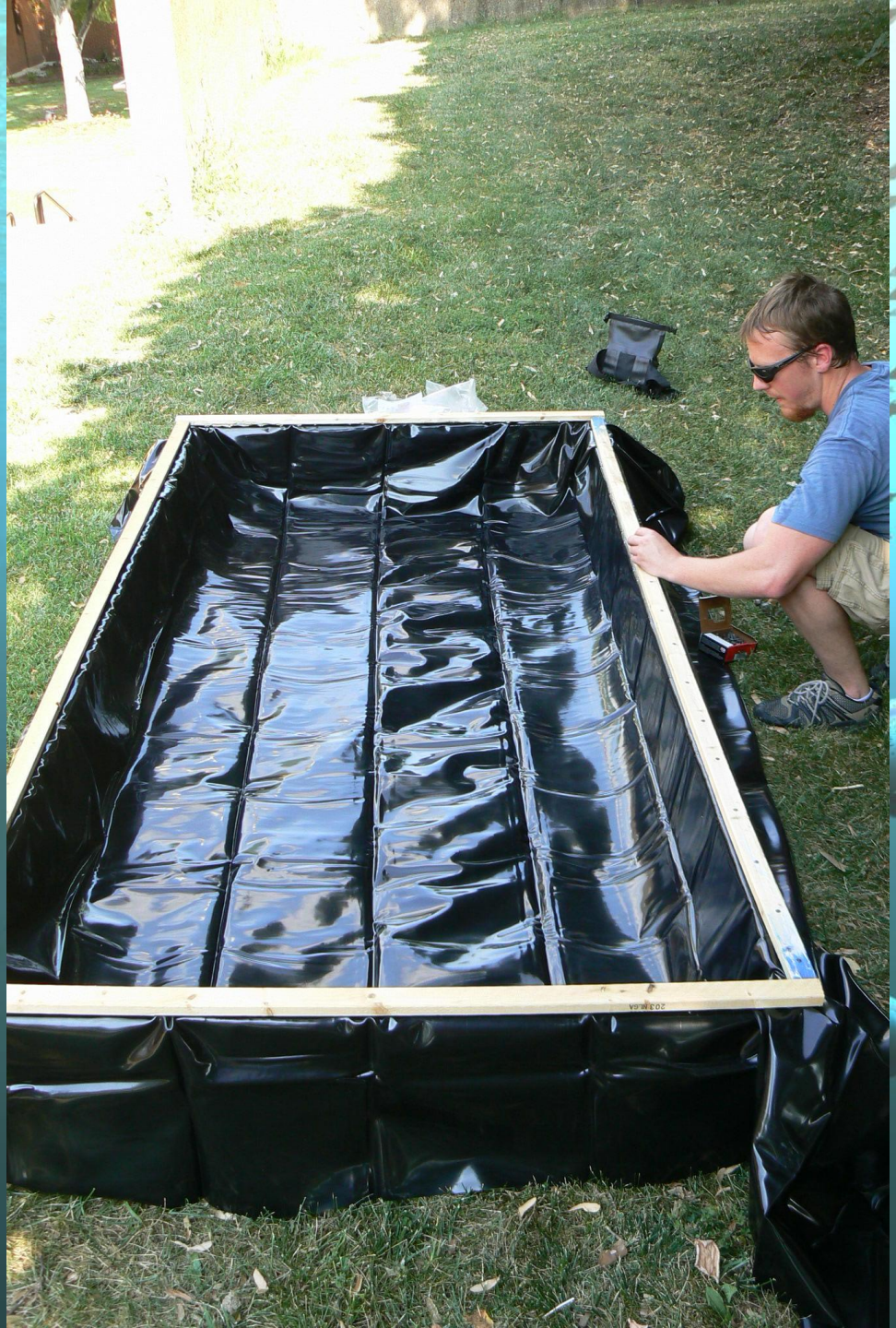
Don't see your favorites? Get the full results at www.foodnews.org & support EWG research with an online gift.

ENVIRONMENTAL WORKING GROUP

PESTICIDES in the DIETS OF INFANTS AND CHILDREN

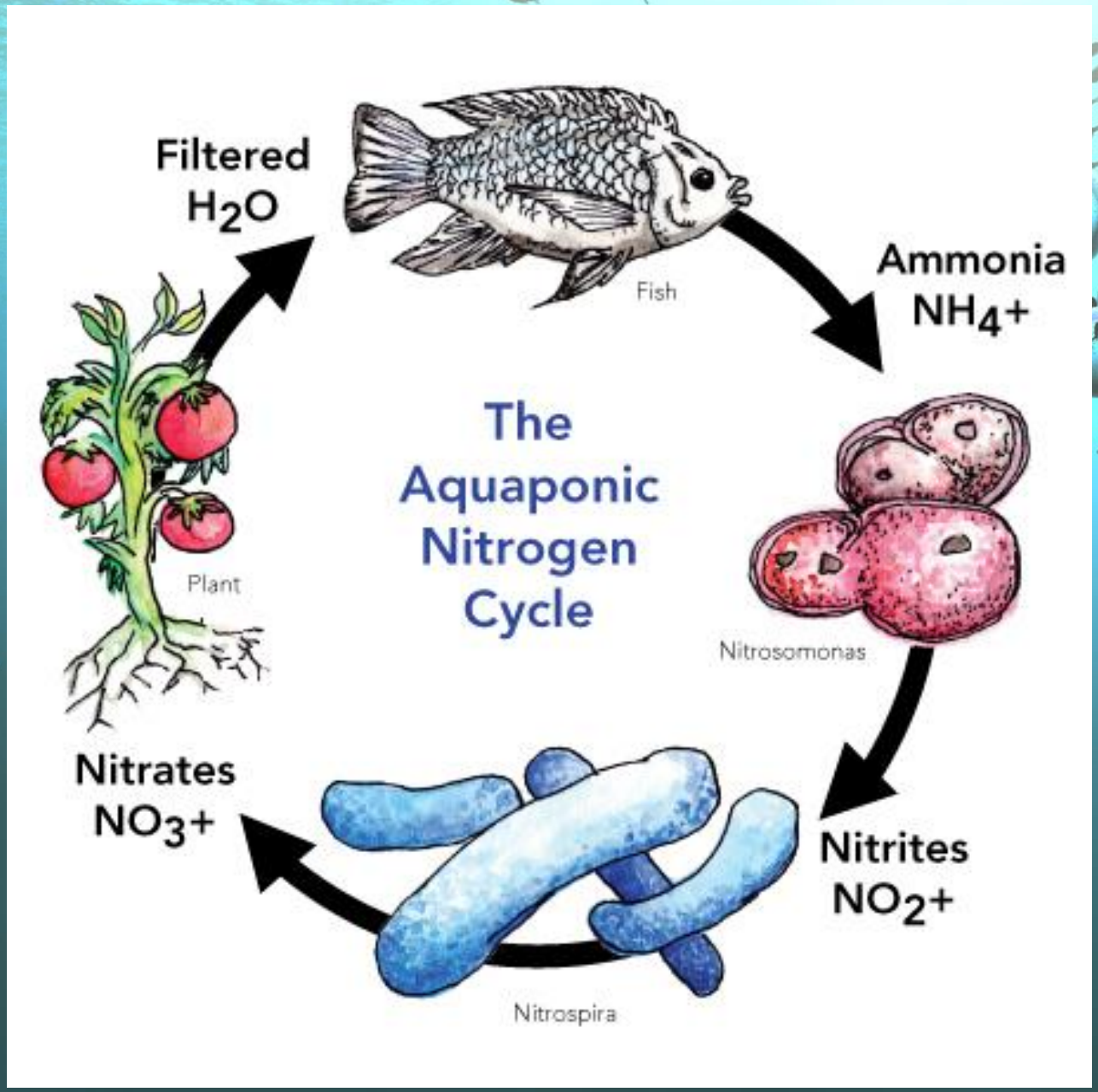
NATIONAL RESEARCH COUNCIL


Here is our first system →




Green Guard

STEM INFUSED ACTIVITIES


Filtered
H_2O
Fish
Ammonia
NH_4+
The
Aquaponic
Nitrogen
Cycle
Plant
Nitrosomonas
Nitrates
NO_3+
Nitrospira
Nitrites
NO_2+

30-Gallon Fish Tank System

- Put fish in your system and wait- the bacteria show up in two to three months.

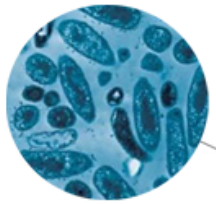
-Or-

- 5-day start up inoculation
  - Add fish; add nitrifying bacteria concentrate when ammonia <3ppm; monitor the nitrite spike; place sprouts into rafts as soon as nitrites first show up (anywhere from 5-20 days)

- Students take measurements for ammonia, nitrite, and nitrate levels in the context of the nitrogen cycle

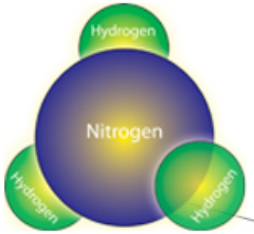
Bacteria

Nitrosomonas and Nitrobacter turn the ammonia into Nitrites and then into Nitrates to be absorbed by the plants effeciently.



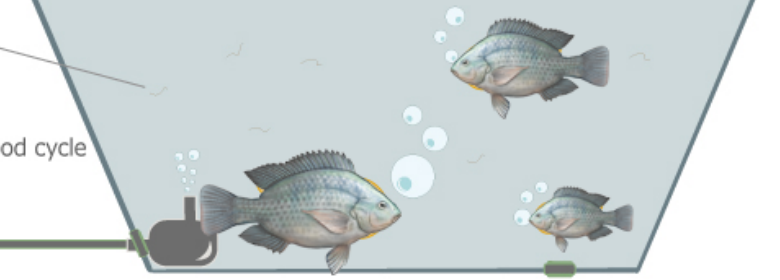
Clean Water

The ammonia and effluents are filtered out by the growing process of the plants. This produces cleaner water which flows down back to the fish tank.



Waste Products

Ammonia : Produced by respiration
Feces : A waste-product of the fish food cycle



Nutrient Rich Water

The eating and respiration of the fish creates waste matter in the form of effluents and ammonia which becomes very toxic to the fish.

This is however very nutritious and is pumped toward the grow bed.

Experimental Variations

Alter variables:

- Amount of bacterial inoculation
- # of fish
- Fish species
- # of plants
- Type of fish food
- Monitor pH changes
- Effect of micronutrients and/or vermicast tea

Growth Experiments

- **Investigations:**

- **Effect of feeding behaviors on growth of fish**
- **Effect of different types of fish feed on fish and/or plant growth**
- **Effect of mono- vs polycultures of fish and/or plants**
- **Effect of water temperature**
- **Effect of stock density**
- **Effect of sunlight and/or artificial light**

Mathematics

Statistical Charts, Graphs, Figures, etc

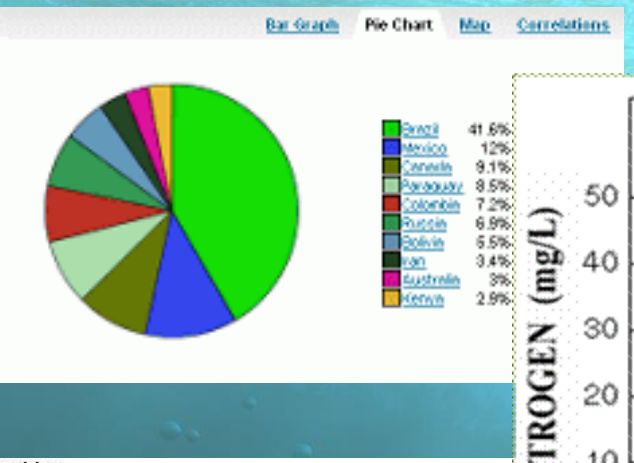
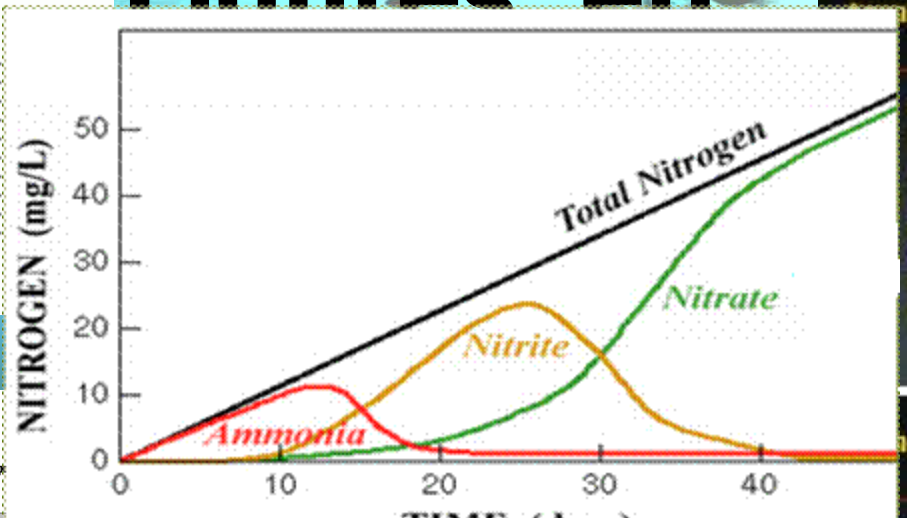
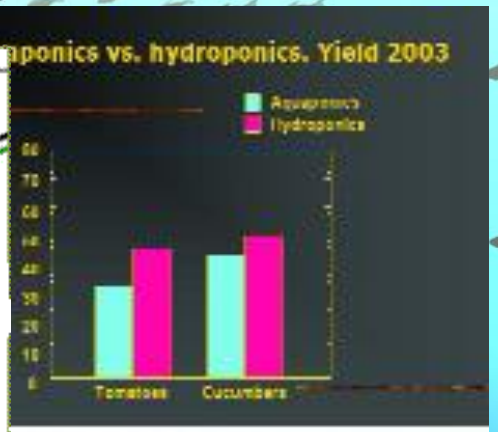
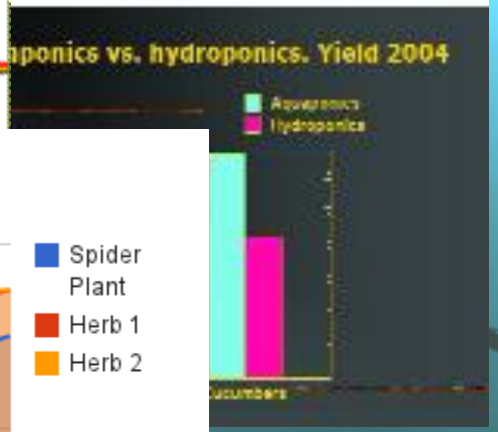
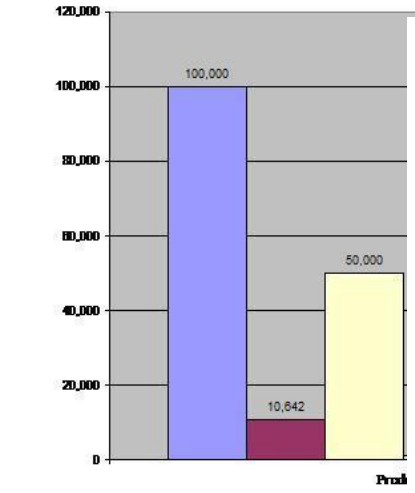


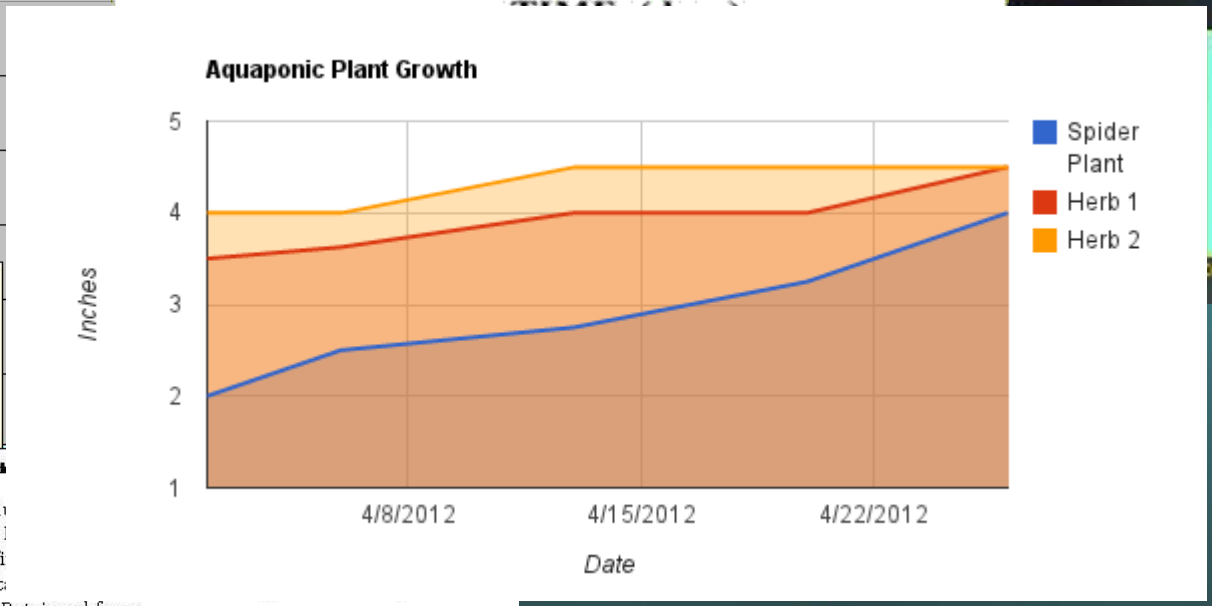
Table 1.
Annual pounds yielded per acre





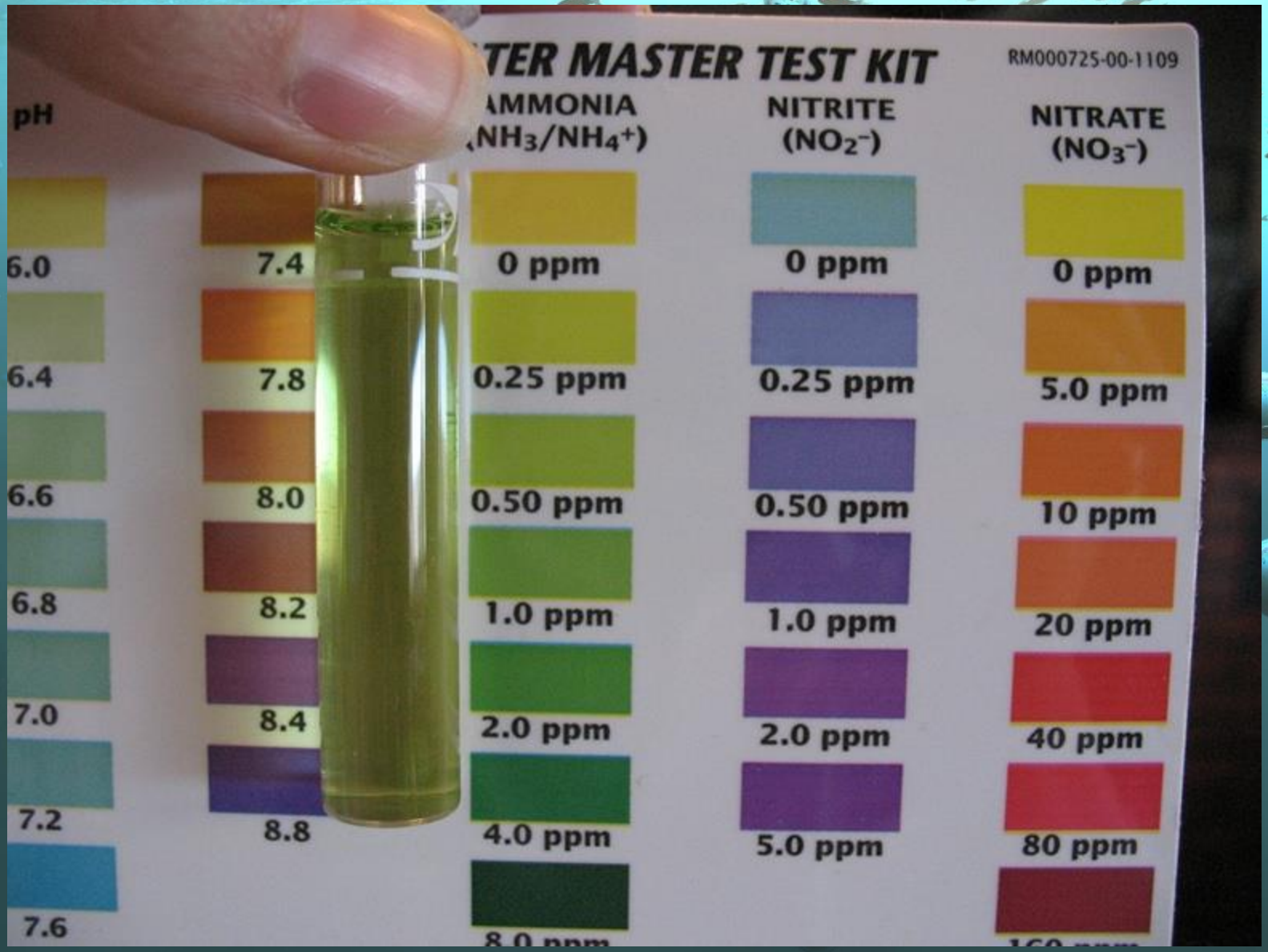






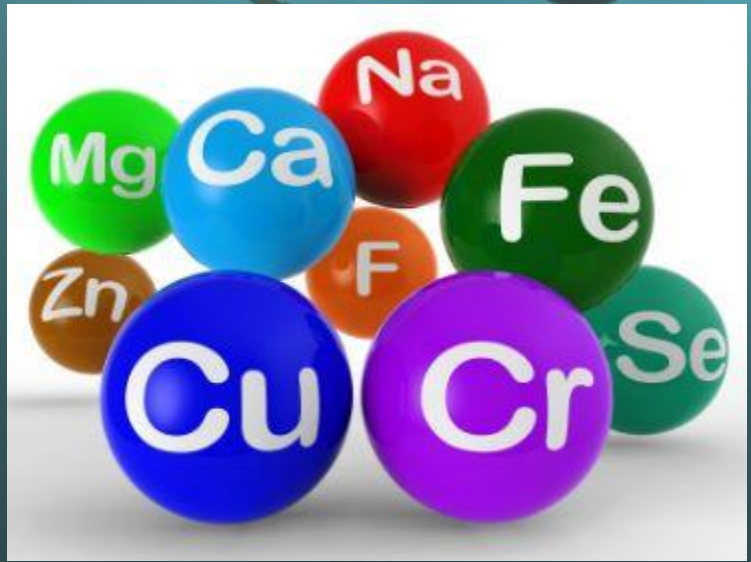
Note. The data on pounds of aquaponic produ
McWilliams, 2009, pp. 161-2. New York, NY:
from Chicama Run, LLC, n.d., Grass-fed and fi
http://www.chicamarun.com/beef.html. Dat
Garden of Eden, n.d., Crop yield verification. Retrieved from:
http://www.gardensofeden.org/04%20Crop%20Yield%20Verification.htm

Chemistry Activities

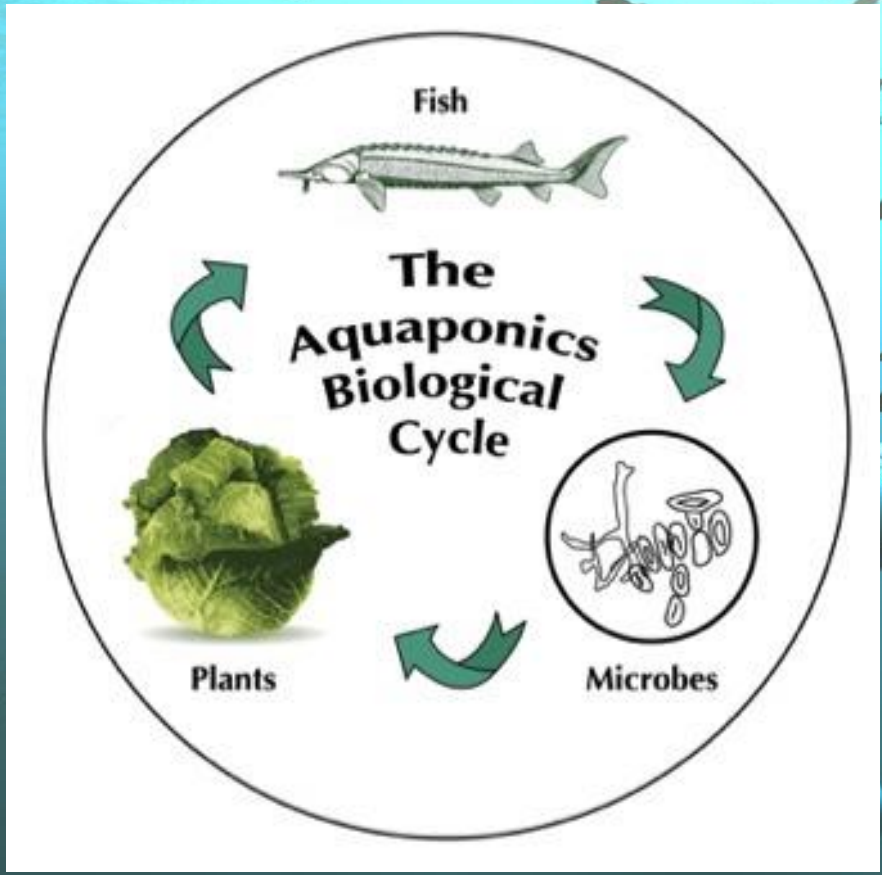


Chemistry Investigations

- **Water quality studies**
- **Effect of dissolved oxygen on (and effect of plants and fish on DO):**
  - **Fish growth and behavior**
  - **Plant growth**



Biological Investigations



Biological Investigations

- What types of fish and/or plants can be grown?
- Fish behavior
- Plant dynamics

Engineering and Technology

- **Aquaponic System Designs**
  - **Relative merits**


Aquaponics
and Health

Aquaponics and Health

Investigations & Case Studies

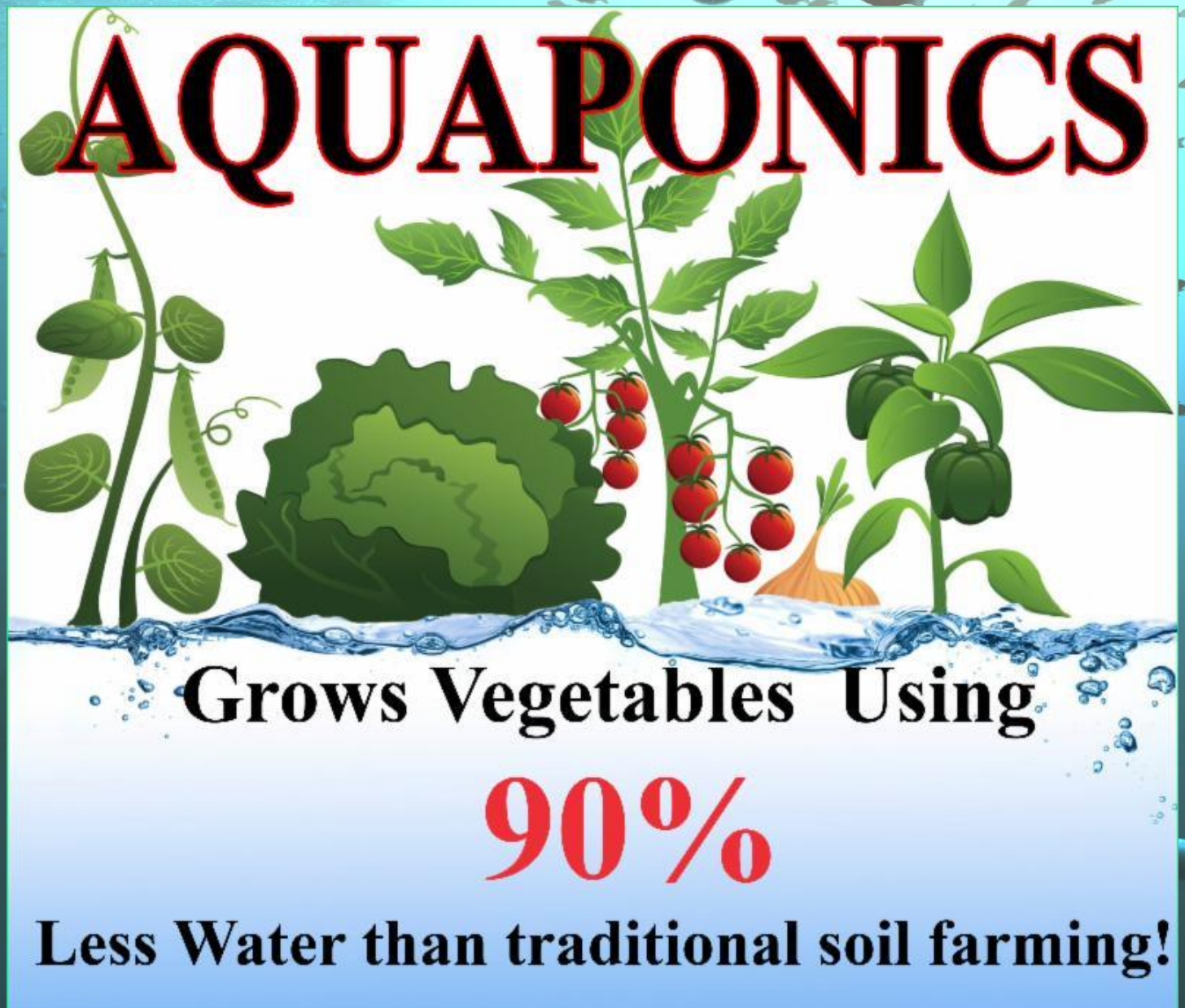
- Food quality
- Food safety

Aquaponics and the Environment

Research Investigations/Case Studies

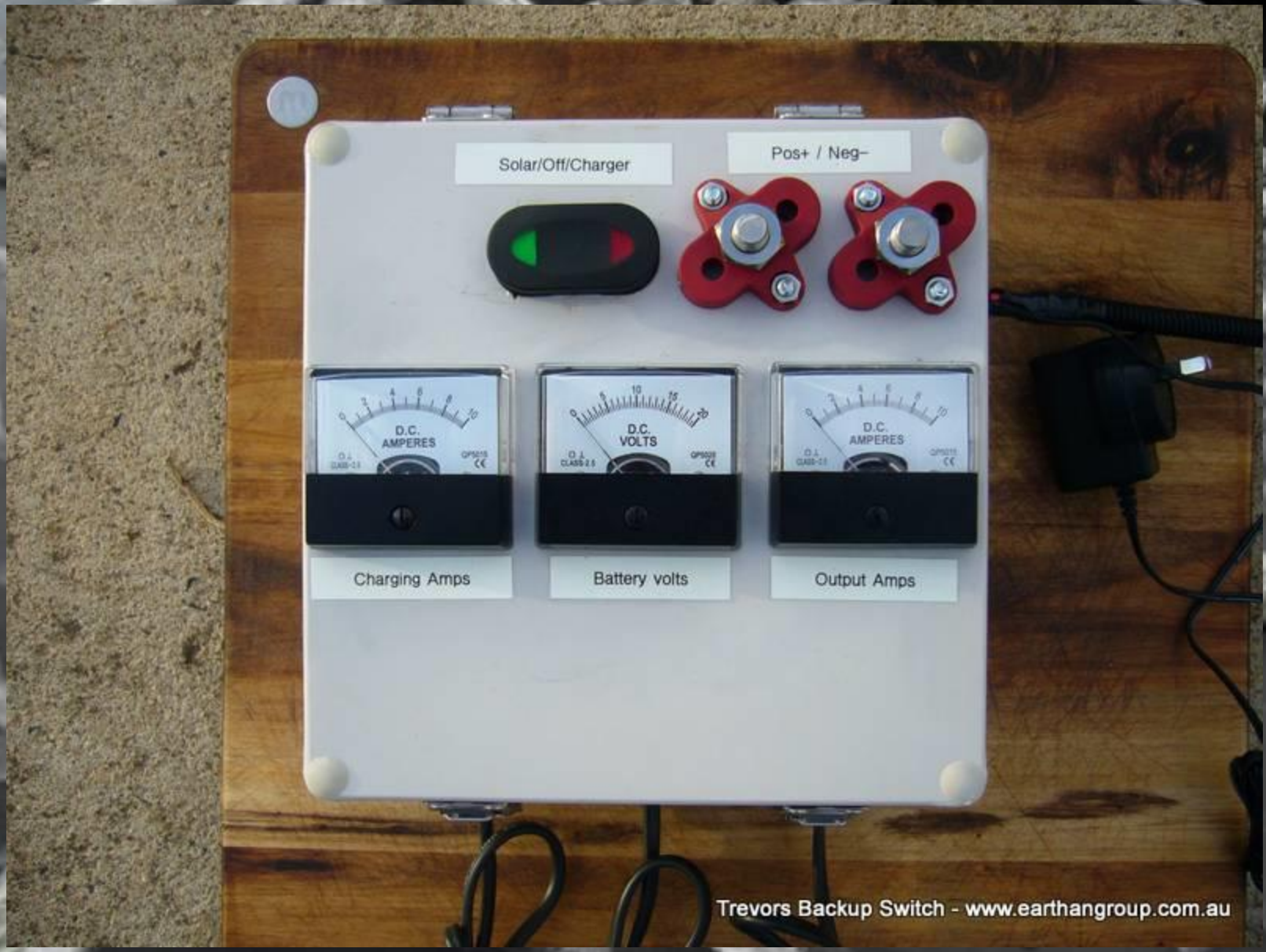
- Water conservation
- No pesticides, herbicides, fertilizers
- Land conservation
- Urban systems

Investigate and Verify



- **Implementation of Aquaponics in Education: An Assessment of Challenges, Solutions and Success**
  - **Emily Rose Hart. 2013. Masters Thesis. University of Massachusetts-Amherst**
- **A.Q.U.A. A Quest to Understand Aquaculture.**
  - **An easy to follow informal aquaculture curriculum for teachers of all grade levels.**

Challenges Encountered


Solar/Off/Charger
Pos+ / Neg−
D.C. AMPERES
D.C. VOLTS
D.C. AMPERES
Charging Amps
Battery volts
Output Amps
Trevors Backup Switch - www.earthangroup.com.au


NITRATE
NO_3^-
TEST SOLUTION
BOTTLE #1
AMMONIA
NH_3/NH_4^+
TEST SOLUTION
BOTTLE #2
API FRESHWATER MASTER TEST KIT
pH
6.0
6.4
6.8
7.0
7.2
7.4
7.6
7.8
8.0
8.2
8.4
8.8
0 ppm
0.25 ppm
0.50 ppm
1.0 ppm
2.0 ppm
4.0 ppm
8.0 ppm
0 ppm
0.25 ppm
0.50 ppm
1.0 ppm
2.0 ppm
5.0 ppm
0 ppm
5.0 ppm
10 ppm
20 ppm
40 ppm
80 ppm
160 ppm

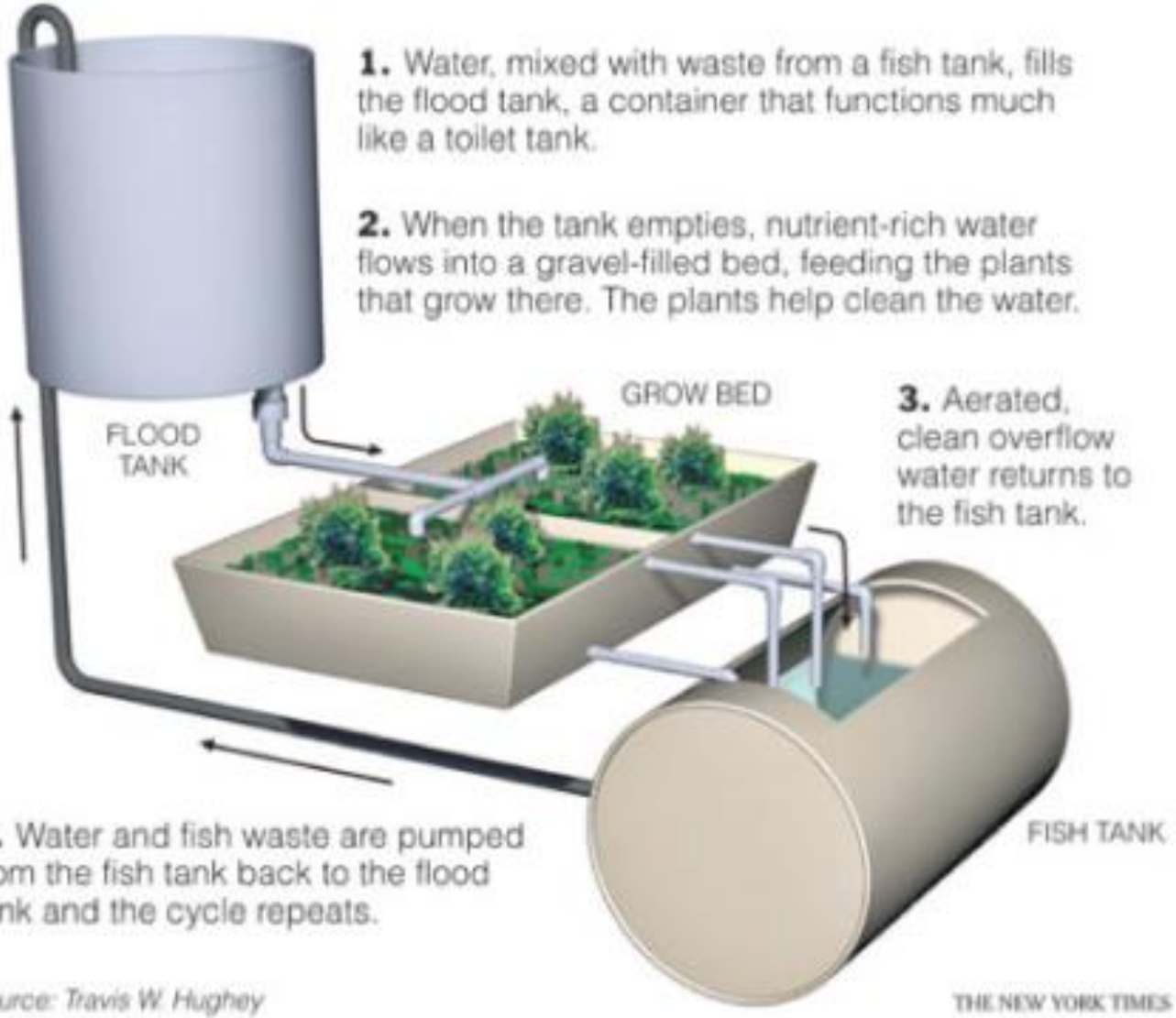

Future Directions

Creating Professional Connections

- Local Industry and Academia
- Career Pathways
- Sustainable Urban Agriculture
  - Modelling different systems

A Sustainable Agriculture

Aquaponics, an inventive form of closed-system agriculture, combines hydroponics and aquaculture — water-based gardening and fish cultivation.



Source: Travis W. Hughey

THE NEW YORK TIMES

A better way to grow

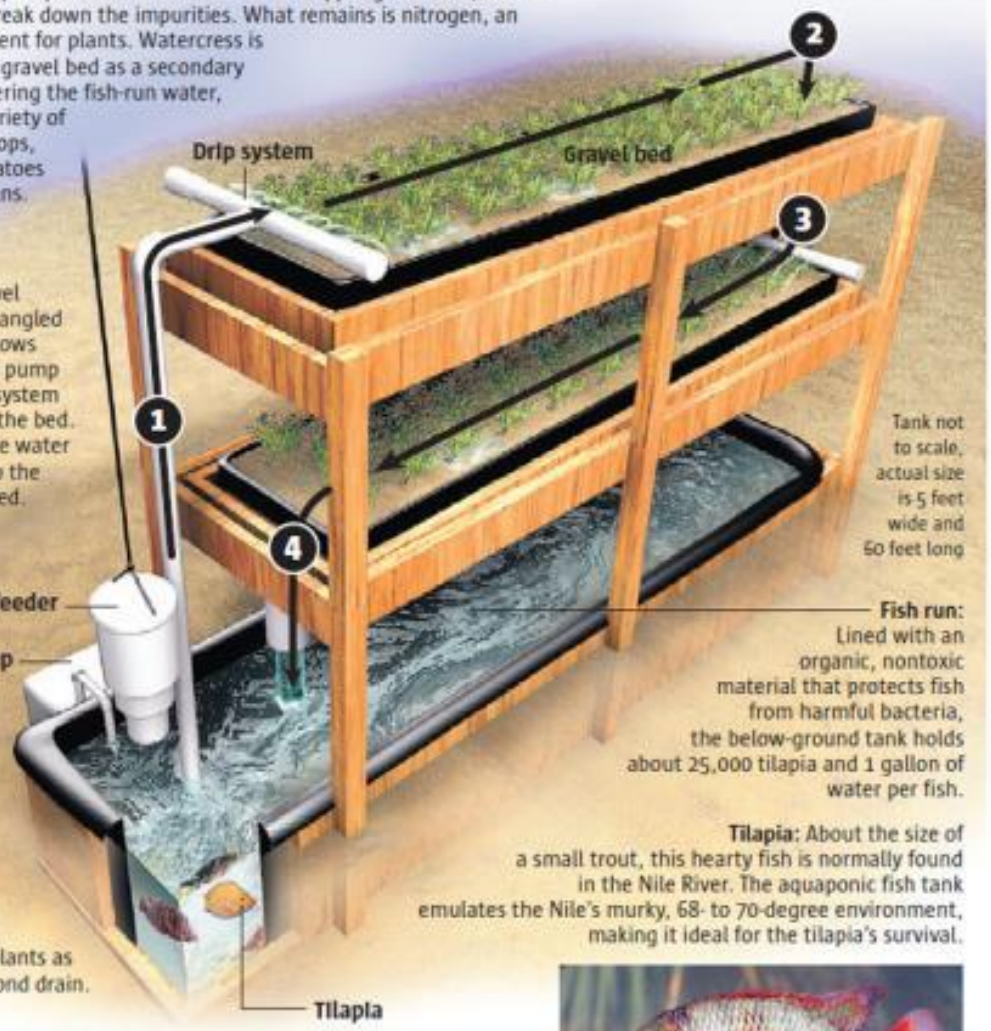
Aquaponics uses a recirculating process to grow and harvest plants, and farm fish. Fish waste works with the beneficial bacteria in gravel and plants, creating a recyclable, concentrated compost.

1
Wastewater is pumped from the fish run to the upper gravel bed, where the bacteria break down the impurities. What remains is nitrogen, an essential nutrient for plants. Watercress is planted in the gravel bed as a secondary method of filtering the fish-run water, as well as a variety of harvestable crops, including tomatoes and salad greens.

2
The upper gravel bed is slightly angled so the water flows away from the pump to a drainage system at the back of the bed. Once there, the water drains down to the lower gravel bed.

3
The lower gravel bed is angled back toward the pump, once again filtering the water and nitrating the plants as it enters a second drain.

4
The filtered water drains from the lower growing bed back into the fish run, and the cycle begins anew. Every nine months, the fish (tilapia and more recently yellow perch) are ready to be harvested.



Tank not to scale, actual size is 5 feet wide and 60 feet long

Fish run: Lined with an organic, nontoxic material that protects fish from harmful bacteria, the below-ground tank holds about 25,000 tilapia and 1 gallon of water per fish.

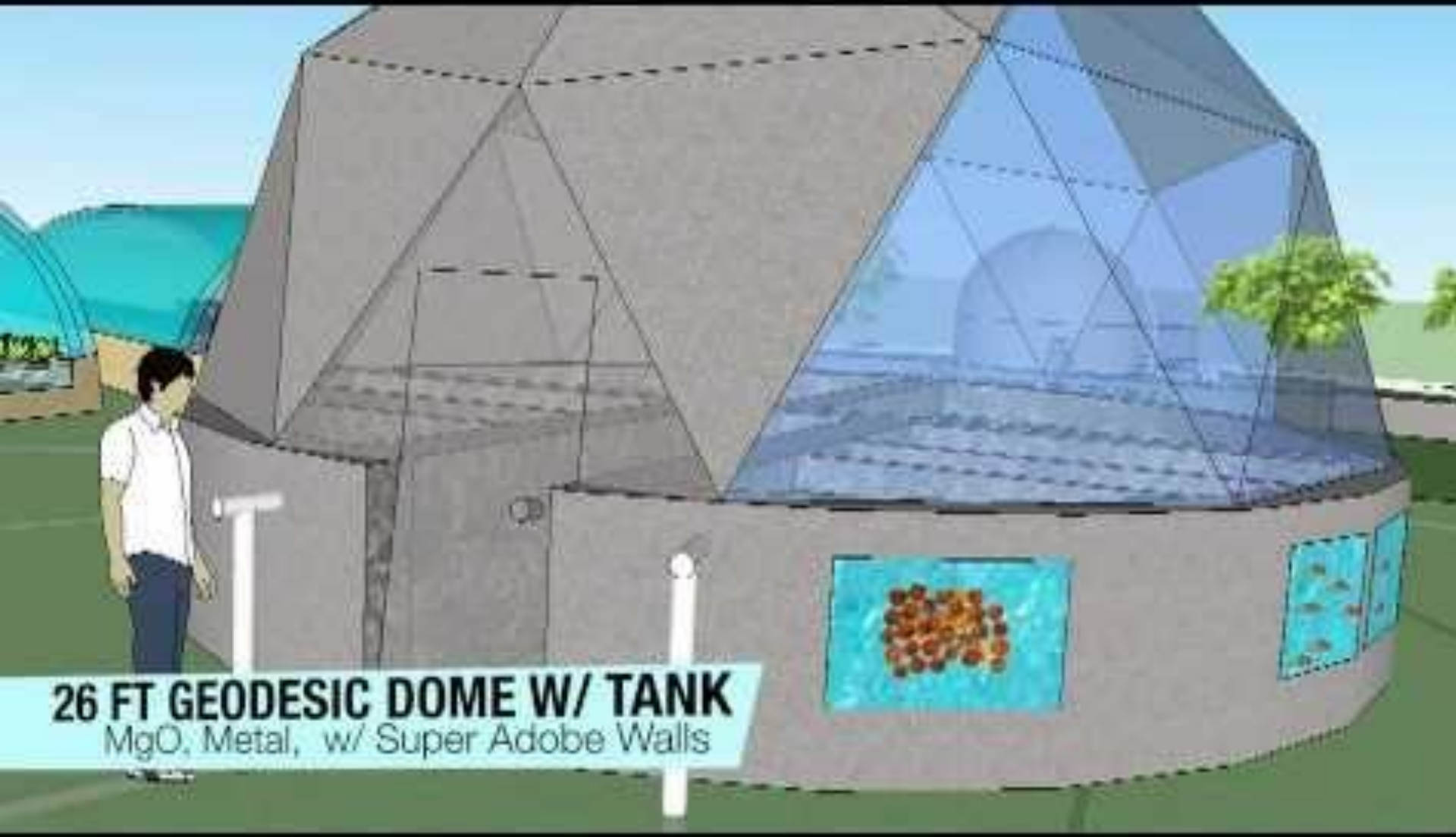
Tilapia: About the size of a small trout, this hearty fish is normally found in the Nile River. The aquaponic fish tank emulates the Nile's murky, 68- to 70-degree environment, making it ideal for the tilapia's survival.

Associated Press photo, Moapa Valley National Wildlife Refuge

Additional text by Colleen O'Connor, The Denver Post

Source: Paul Tamburello, founder Urban Organics, Growing Power Inc.

Jonathan Moreno, The Denver Post


26 FT GEODESIC DOME W/ TANK
MgO, Metal, w/ Super Adobe Walls


NSF Grant

FOOD DESERT SOLUTIONS

SEVEN STEPS TOWARDS PUTTING HEALTHY FOOD IN GOOD HANDS

COMMUNITY

FOCUS ON LOCAL AGRICULTURAL SOLUTIONS TO DECENTRALIZE SUPPLY AND INCREASE THE AVAILABILITY OF QUALITY FOOD.

1. **GROW FOOD LOCALLY**
   Build and develop backyard and community gardens as well as larger scale urban agriculture

2. **DEVELOP ALTERNATIVE RETAIL OUTLETS**
   Farmers Markets, Public Markets, Cooperatives, Farm Stands, and Community Supported Agriculture (C.S.A.) Programs

ACCESS

INCREASE THE EASE OF OBTAINING QUALITY FOOD.

3. **REPLACE "CONVENIENT" WITH QUALITY**
   Increase stocks of fruits and vegetables at corner stores or small groceries

4. **MORE FULL-SCALE GROCERY STORES**
   Attract and/or develop more grocery stores and supermarkets where they are scarce.

5. **TRANSPORTATION**
   Improve transportation to grocery stores and farmer's markets

EMPOWERMENT

EQUIP INDIVIDUALS AND FAMILIES WITH THE TOOLS TO MAKE HEALTHIER FOOD CHOICES.

6. **COOKING CLASSES**
   Implement programs at shelters, churches, community colleges, & civic centers teaching people how to cook cheap, simple, and healthy meals.

7. **NUTRITIONAL EDUCATION**
   Teach classes on nutritional information including the dangers of preserved and fast food while stressing the healthy benefits of freshly prepared meals.

Aquaponics: A Sustainable, Low-Impact Agricultural Solution to Food Deserts and Urban Decay

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Abstract

The word 'aquaponics' is the combination of aquaculture, the cultivation of aquatic organisms (fish or shellfish) for food, and hydroponics, the growing of plants in nutrient solutions with or without an inert medium or soil (Merrian-Webster, 2012). Aquaponics systems are exceptionally efficient, producing more vegetables per square foot than other forms of agriculture, although the environmental impact is much lower. As a self-contained system, it requires no use of chemical fertilizers, eliminates the possibility of soil-borne pathogens and uses only 1% of the water consumed by conventional agriculture. Depending on the system's size and design, it is possible to grow up to 10,000 fish and up to 43,000 pounds of vegetables per year. (Allen, 2012) Growing food locally -- where it is consumed -- eliminates cost and environmental impact associated with transportation, providing affordable fresh food. Aquaponics systems are highly adaptable to geographic region. Repurposing older vacant and abandoned buildings with aquaponics production can bring sustainable economic activity back to former industrial areas, while providing a local source of affordable fresh food that eliminates food deserts.

About Aquaponics Systems

Aquaponics systems are a low-cost, high output food production system that greatly improves the affordability of food production with limited waste and a very low environmental impact. As closed-loop, freshwater aquatic ecosystems, they eliminate any water run-off and use just 1% of water used by conventional agriculture to produce a similar yield (Allen, 2012). Figure 1 models the basic components of an aquaponics system.

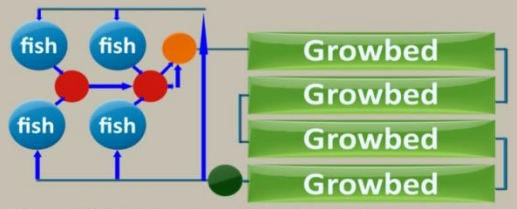

Figure 1: A simplified model of a closed-loop aquaponics system *(Graphic: Shawn Kargus)*

Gravity forces water from the fish tanks (blue circles in Figure 1, illustrated in Figure 3) to the filter tanks (red circles), then to the bio-reactor, a non-pressurized bio-filter (orange circle). The nutrient-enriched water then flows into the grow beds, where it is cleaned by the plants (illustrated in Figure 4), which extract the fish waste for use as fertilizer, the now-clean water flows into the sump tank, the lowest point in the system (green circle). The cleaned water is then pumped back into the fish tanks by a 1/3 horsepower pump, completing the loop.

Systems Implementation

Aquaponics systems are highly adaptable to geographic region. In warmer climates, growing can be accomplished outdoors by utilizing vacant land or abandoned parking lots. In colder climates, with the use of growing lights, vacant factories can be converted to indoor growing facilities. Greenhouses can the limit need for extra lighting.

The current high-output commercial-sized aquaponics systems are very expensive, ranging from $27,000 to $98,000 and higher (Pade, 2012). By improving key system components, such as inventing a new filter system and low-head bio-reactor to improve aeration (patents pending), the researcher has developed a system for $8,200 with the same output as more expensive commercially available set-ups.

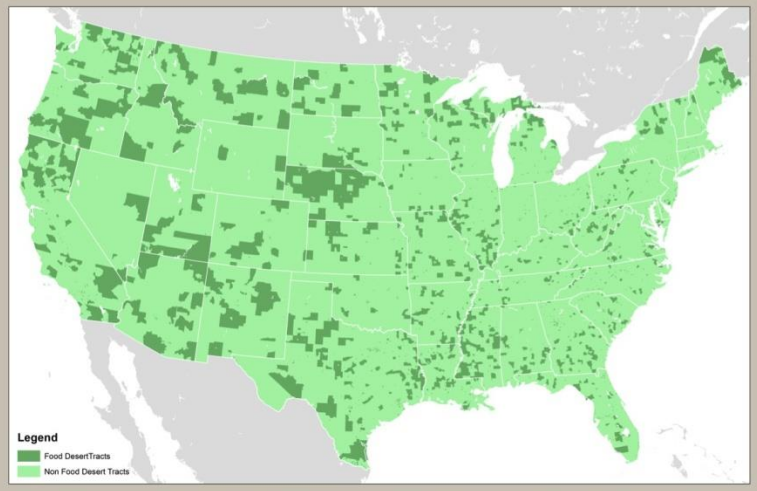

Figure 2: Census Tracts in United States that are considered "food deserts" by the U.S. Department of Agriculture *(Data: USDA and US Census Bureau; Map: Shawn Kargus)*

The Problem of Food Deserts

A food desert, as defined by the United States Department of Agriculture, is an area with limited access to affordable and nutritious food, particularly if such an area is composed of predominantly lower income neighborhoods and communities. *(USDA, 2012a)* The scarcity of affordable, healthy food options in urban communities is not a problem with the food production system, but rather how the food is distributed. In fact, in the United States, food production outpaces total population growth. With reduced access to healthy food options people are eating what is convenient and affordable; "fast food" that lacks nutritional value and is high in fat. Figure 2 shows U.S. Census Tracts considered food deserts.

Figure 3: One of four installed 500 gallon fish tanks, part of a commercial system that can produce up to 2,000 pounds of fish and 30,000 pounds of vegetables annually *(Photo: Shawn Kargus)*

Figure 4: Media filled grow bed of a commercial trench aquaponics system. Vegetable roots remove fish waste from water, fertilizing plants and cleaning the output *(Photo: Shawn Kargus)*

Figure 5: A 520 gallon home-based system able to produce 500 pounds of fish per year, plus 20 to 40 pounds of vegetables per week *(Photo: Shawn Kargus)*

Benefits, Efficiency and Yield

One large aquaponics installation can produce of up to 30,000 pounds of vegetables and 2,000 pounds of fish, with this density of production, up to 200,000 pounds of food can be grown per acre of land. In addition, this production is deployable everywhere, so food can be produced close to the point of consumption, creating local jobs, saving transportation costs and reducing CO_2 emissions. High-density food production at the point of consumption will significantly lower the cost of produce. According to the USDA (2012b), $0.19 of every dollar spent on food goes to food processing, $0.04 goes to transportation, $0.14 goes to food retailers and $0.34 goes to the food service industry. Aquaponics systems could potentially eliminate $0.67 from every dollar of food costs.

Beyond a high density of production, aquaponics has very low environmental impact. It avoids many negative impacts of conventional agriculture, specifically pollution caused by the use of synthetic fertilizers, herbicides, fungicides and pesticides. The system uses less water and energy than conventional agriculture and does not erode soil. Aquaponics eliminates the solid waste byproduct found in traditional land-based hydroponics. The closed-loop system eliminates parasite problems, chemical inputs or fish waste concentrations found in the ocean-based aquaculture and deep-sea fish farms, which are responsible for environmental destruction and wild-fish kills.

A Solution to Food Deserts?

By offering a lower price for aquaponics systems with the improvements I have developed, more people will have access to this food production method. A system that can produce high yields of both fish and plants makes food less expensive and more affordable to the people in the community in which the food is grown. Implementation of these low-cost systems can bring affordable and fresh food to areas now considered "food deserts," helping to solve food distribution and accessibility issues. An easily deployable 520 gallon system (Figure 5) produces fresh food to feed a family of four.

In addition to the food grown by the system, this intensive agriculture creates economic opportunity by providing jobs for people in the community. Opportunities will exist for jobs in system building, maintenance, construction, sales, marketing, production and job training. Growing food in the community it is consumed also reduces CO_2 from transportation, further reducing the the environmental footprint of a food production system that is, which by design, safe and sustainable.

The researcher is seeking grant funding through the Environmental Protection Agency to further explore the practical application of aquaponics systems for eliminating food deserts and revitalizing urban areas.

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Redbreast Tilapia (Oreochromis spp.)
(Illustration: Fisheries Hartebeest, 2009)

Questions, Comments, Suggestions, Ideas