

Co-Evolutionary Design


Guest lecturer: Susan Murcott, Principal Investigator and Research Engineer in MIT's Civil and Environmental Engineering Department; focuses on water and sanitation engineering projects in developing countries

This lecture is based on one given by Susan at the *Engineers for a Sustainable World* conference (Stanford University, Oct 1 2004).

This talk is about taking the design process through the stages that her design teams have gone through. It should be a hopeful message, because the talk shows all the hard work that happens in the process of bringing an idea into the field.

20th c Western engineering design used to be based on fairly straightforward criteria of cost and performance.

Back in the days of the 20th century, Western engineering design was comparatively simple.



Technical Criteria

Economic/Financial Criteria (Cost-Benefit Analysis)


In the 70s, E.F. Shumacher published *Small is Beautiful* which introduced the idea of "appropriate technology" and in that same era, environmental considerations were newly brought into public awareness and the design process.

Design Principles for Appropriate Technology
 (after E.F. Schumacher: [Small is Beautiful, 1973](#))

1. Simple design & production
2. Low cost
3. Use local materials for local use
4. Rural focus: Technologies and workplaces must be created in areas where people are living now, not primarily in urban areas

In the 80s and 90s, sustainable development considerations have been added. What's sustainable development about? It's a balance among economic, social and environmental aspects.

Environmental Awareness, codified into laws and regulations beginning in the 1960s in the U.S., added another dimension:




Technical

Economic/Financial Criteria (Cost-Benefit Analysis)

Environmental / Green Design

"Sustainable development" has 2 widely accepted meanings:

Balance: economic, social, environmental aspects



Equity... "meeting the needs of the present without compromising the ability of future generations to meet their own needs."

- Our Common Future, 1987

"Engineering design for sustainable development" framework



Financial/Economic

- Cost, subsidies, taxes, profitability, etc.
- Provides local jobs?
- Support local economies?

Technical

- Standards and Guidelines
- Quality Assurance/Quality Control
- Operation and Maintenance
- Materials/parts availability

Social

- Customer satisfaction
- Simple/convenient/user friendly
- Durable

Susan is a water engineer; she is continually asking, "Who needs the development for water projects?" These questions lead to a "co-design" or "co-evolutionary" design process.

It may be that for a new cell phone or computer chip, you can design it in the lab; but you can't do that for a water project, moreover, you can't be a 1st World engineer designing for a 3rd World community, without engaging the community and the users in a co-design or co-evolutionary process.

Problem Awareness through Partnership

What's the country/region/community? What are the problems? In Nepal, where's the arsenic? How does this problem also affect South Asia, New Mexico, New Hampshire? How does the arsenic affect people?

Partnerships with local organizations are central to doing this work, to getting awareness.

Problem Co-definition

In year 2, 3, 4 of a project, the perspective of co-definition leads to continuous refinement in understanding the problem and potential solutions. Statements about application, technical performance, cost, manufacturability and social acceptability all evolve toward the most appropriate solution.

Take the case of water development projects in the 1980s. The U.N. goal was all about water supply and microbial safety, with a strong bias that groundwater was inherently better than surface water sources like rivers. Water quality testing being hard and expensive, it wasn't done extensively...of the millions of wells in Bangladesh, it took 15 years of using these new water supplies before arsenic testing was put in place. Don't lose sight that millions of childrens' lives were saved by alleviating the microbial contamination that resulted from switching from very dirty surface water sources to groundwater supplies; but realize there are also potential unintended consequences and so many other things to also watch for.

Now there are hundreds of millions of people around the world affected by arsenic-contaminated

Co-Designing/Co-evolving for Development (an iterative process)



Problem Awareness - Arsenic in South Asia

Pre-1970s: Surface water for drinking, caused many diseases
 1970s: Groundwater was tapped as a safe, pathogen-free alternative for drinking
 1980s: Naturally occurring arsenic found in groundwater
 1990s: Millions of people found affected, serious disaster



Problem Awareness – Arsenic

- Source: Natural
- Toxicology
 - Poison
 - Skin disease such as melanosis, keratosis
 - Vascular diseases
 - Cancer to lung, bladder
- World Health Organization guideline: 10 ppb
- Nepali interim guideline: 50 ppb
- Nepal Terai Region
 - 25% tubewells > 10 ppb (1.7 million people)
 - 8% tubewells > 50 ppb (0.5-0.7 million people)

Problem Co-Definition

- Our proposal is to design a household drinking water treatment unit to remove arsenic and pathogens.
- Technical Performance: Remove arsenic, bacteria and parasites to National Standards or WHO Guidelines;
- Water Quantity: The flow rate should be > 10 L/hour;
- Cost: The cost/unit should be < \$30. Yearly replacement parts < \$2, designed for rural areas and urban slums for those who earn < \$2/day;
- Manufacturing: Produced by local people, using locally available materials, creating local jobs;
- User friendly: Socially acceptable to women and children users.

Problem Co-Definition Arsenic Technology Database

- Gather information for 50+ technologies:
- Arsenic removal mechanisms (physical, chemical, etc)
 - Technical performance
 - Construction, operation and maintenance
 - Cost
 - Flow rate
 - Strengths, weakness, limitations

<http://web.mit.edu/murcott/www/arsenic>

groundwater supplies.

Susan has supervised many arsenic-related thesis projects, with months-long field testing experiences. For example, iron filings (scrap from iron fabrication) and iron-heavy sands are among the materials being evaluated.

(3) Idea Co-Generation 8 Arsenic Removal Technologies

- (1) 3 *Kolshi* (in Nepali = 3 *Gagri* with zero valent iron filings);
- (2) Iron filings in jerry can;
- (3) Coagulation Filtration (2-*Kolshi* based on Chakraborti's arsenic removal system);
- (4) Iron oxide coated sand;
- (5) Activated alumina metal oxide #1 (Apyron Inc.);
- (6) Activated alumina metal oxide #2 (Aquatic Treatment Systems Inc.);
- (7) Arsenic treatment plant;
- (8) *Kanchan*TM Arsenic Filter

How does an idea get refined? In a three-pitcher or 3-kolshi vertical filter with sand and iron filings, problems included a slow flow rate and being prone to clogging. Furthermore, iron filings originally obtained from Pennsylvania were not locally available in Nepal. What kind of local iron products are available as alternative? They found a nail shop w/ both galvanized and ungalvanized nails. Rusty ungalvanized nails are a great adsorption media for arsenic removal.

Three-Kolshi (Gagri) System

Raw water → Iron filings → Fine sand → Filtered water

Jerry Can

1. Fill 10L plastic jug with raw water.
2. Add iron filings
3. Wait 3 hours
4. Decant treated water

Coagulation/Filtration (2-Kolshi)

Chemical packet → Raw Water → Mixing & Settling → Filtration → Treated Water

Iron Oxide Coated Sand (IOCS)

Raw Water → Sand and gravel → Iron Oxide Coated Sand (IOCS) → Treated Water

Activated Alumina Metal Oxide #1 (Apyron Aqua-Bind Media)

Raw Water → Sand → Activated Alumina → OAC → Treated Water

Activated Alumina Metal Oxide #2 (Aquatic Treatment Systems, Inc.)

Raw Water → Alumina Manganese Oxide (A/M) → Treated Water

Arsenic Treatment Plants (ATPs)

Aeration Chamber → Storage → Sand Filter → Treated Water

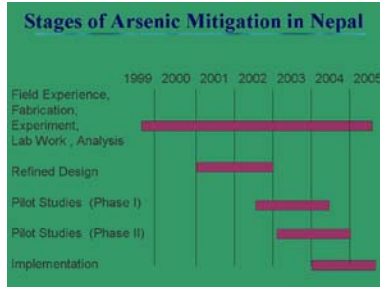
KanchanTM Arsenic Filter (KAF)

Concept Co-Evaluation

The class looks at Pugh Chart comparisons of working water filter designs through Fabrication, Lab Work, Analysis, Refined Design, Pilot Studies, and Implementation.

Design Concept Co-Evaluation Matrix
(also known as a "Pugh Chart")

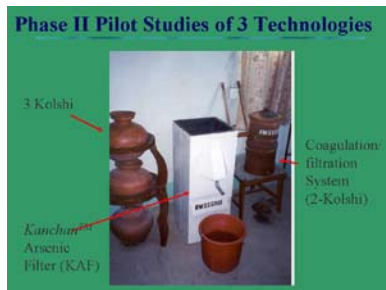
Evaluation Criteria	Datum	Option 1	Option 2	Option 3
	3-Kolshi	Coagulation-filtration	Activated Alumina	Iron-coated sand
Water quality	0	0	-	0
Water quantity	0	+	+	+
Capital cost	0	+	+	+
O&M cost	0	+	-	+
Local jobs	0	+	0	+
User friendly	0	+	-	+
Total	0	+0	+1	+1



Phase I Evaluation Summary

Technology	Technical	Social	Cost	Recommend for Phase II?
3-Kolshi	✓	✓	✓	✓
Jerry Can	✗	✗	✗	✗
Iron Coated Sand	✓	✗	✓	✗
Alumina #1	✓	✗	✗	✗
Alumina #2	✓	✗	✗	✗
2-Kolshi	✓	✓	✓	✓
Treatment Plants	✗	✗	✗	✗
AKF	✓	✓	✓	✓

In a comparison of technical, economic, and social criteria, three of the eight designs excelled. These three were pushed ahead into Phase II evaluation and pilot studies.



Phase II Evaluation Summary

	3-Kolshi	2-Kolshi	AKF
Arsenic removal	95-99%	80-90%	90-95%
Iron removal	Not tested	Not tested	93-99%
Flow rate	1-5L/hr	1-5L/hr	10-15L/hr
Materials availability	***	*	***
Easy construction	***	***	***
Simple O&M	***	***	***
Long term sustainability	**	*	***
User acceptance	**	*	***
Low initial cost	***	***	***
Low running cost	**	***	***
Overall Ranking	2nd	3rd	Best

* = poor ** = moderate *** = good

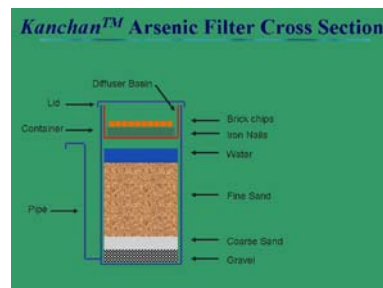
KAF Pilot Study Results (n=16)

Technical Indicators	Average Results
Arsenic Removal	93 %
Total Coliform Removal	58 %
E. Coli Removal	64 %
Iron Removal	93 %
Flow Rate	14 L/hr

What are the expectations on water quality, i.e. coliform removal? The WHO has a recently updated spec, 3rd edition, which acknowledges different communities have differing abilities to realize targets...accommodates some collaborative planning. See http://www.who.int/water_sanitation_health/dwq/en/.

Slide shows a diagram of "Kanchan" Arsenic filter; this was a winner in MIT IDEAS competition, ~2003, which gave working funds for refinement and Phase II.

Q: Why have coarse sand and gravel at the bottom, below the fine sand?
A: These coarser media are simply there to protect the pipe.



The World Bank “development marketplace” competition in 2003 awarded \$115k to the Kanchan Arsenic Filter. In the contest, there were 85 finalists and 42 winners out of ~2,700 applications.

Tommy Ngai, the student that led the group, has been in Nepal for the past 2 years, working with local partners to refine the design and build local resources. Design has evolved from custom-made concrete (too expensive, too slow to build) to a plastic bucket design. Sloan School “G-Lab” students have contributed in the past couple of years.

Major Accomplishments

2. *Researched and developed the Gem505 Design*
 → better performance, lower cost, improved acceptance




Concrete Square (2002) Concrete Round (2003) Plastic Hiltake (2003) Plastic Gem505 (2004)

Major Accomplishments

3. *Train 15 local entrepreneurs from arsenic-affected districts on filter construction, troubleshooting, water testing*

Selected based on SOA2003 and Nepal Census 2001 data including:

- Population affected
- GPS mapping
- Vulnerability
- Household income
- Arsenic awareness level
- Literacy level
- Health statistics



4. *Conduct workshops to 30 VDCs and 178 wards on health, water management, treatment options, and filter information*

Major Accomplishments

5. *Over 2,000 filters distributed, serving 15,000+ beneficiaries (as of Jan, 2005)*

RYBSSP distribution (since 2002)	700+
Nepal Red Cross Society distribution (since 2003)	500+
DM project distribution (since April 2004)	350+
Entrepreneurs (since April 2004)	450+



This project has trained 15 local entrepreneurs; taught workshops in ~30 communities; distributed 2,000+ filters as of Jan. 2005.

Now they are conducting a User Survey. Preliminary results are considered very favorable: 85% of filters are still in operation, and 82% of users would recommend filter to others.

Preliminary User Survey Results

Preliminary results (n= 424) as of Jan 31, 2005

	Yes	Partially	No
Filter still in operation after 1 year	85.3%	8.3%	6.3%
Users think filter operation is easy	73.6%	—	25.4%
Users can operate the filter correctly	50.2%	42.3%	7.4%
Users will recommend filter to others	82.5%	—	17.5%

	Better	Same	Worse
Appearance of filtered water	92.8%	5.9%	0.2%
Taste of filtered water	96.0%	5.0%	0%
Smell of filtered water	89.9%	11.1%	0%
Users' perceived health conditions after drinking filtered water	77.5%	22.5%	0%

Summary


Does the filter meet our goals for Co-Evolutionary Design? It seems so...the unit costs about \$16 to make, and the entrepreneur makes ~\$5 profit. At this early stage, the entrepreneurs use this as a side business rather than their sole source of income. But the goal is for a tremendous ramp up – only 2000 units so far, but they hope to reach 700,000 people.

Entrepreneurs' Financial Sustainability?

Financially sustainable
 Margin per unit X unit sales = Fixed cost

In our case

- Fixed cost is minimal because the entrepreneurs are well-established organizations with their own financial support for their premises and staff
- Temporary staff can be hired to construct filters based on demand



Kanshan is not the sole solution for Nepal – other technologies may be more appropriate in other situations. And the same goes for other countries.

Related links:

MIT Civil and Environmental Engineering (CEE) web portal on household water treatment and urban and rural sanitation projects in developing countries. <http://web.mit.edu/watsan>

Arsenic Biosand Filter Project, via World Bank http://web.mit.edu/watsan/worldbank_summary.htm