聲明

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行政院環境保護署
Environmental Protection Administration
Executive Yuan, R.O.C.

2012 Research and Training Course for the Area of Southeast Asia-Environment Analysis and Green Technology 14, Nov. 2012

Green Chemistry toward Sustainability

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Outlines

I. Recent Major Thrusts of Taiwan EPA

（Welcome Remarks and Introduction）

II. Some Interested Areas of Research by Dr. Roam

（Nano, Anaerobic, AOP, Colloid, Risk Assessment）

Ⅲ. Roadmap and Case Studies of Green Chemistry

(Two-track System＆US Presidential Awards)

Ⅳ. Waste Treatment＆Resources Recovery

（Phosphorus from Domestic and Industrial streams）

Ⅰ.Recent Major Thrusts of Taiwan EPA

1.Promoting National Sustainability

- Organization Reshuffle：Ministry of Environment and Resources （2013）
- National Sustainable Development Council（NSDC）：Secretariat of NSDC.
- Environmental Impact Assessment（EIA）：Policy assessment/case assessment.
- Science＆Technology Research / Development：Nanotechnology, Environmental Forensic Technology, etc.
- International technical cooperation：180 projects have been implemented since 1995 with USEPA.

2.Energy Saving and Carbon Reduction

- Green Gas Reduction Act.（draft）
- Nationwide promotion program：Ecolife network

3.Resources Recycling and Zero Waste Policy

- Domestic and Industrial Waste Recycling.
- Building New island as Finial Disposal Site.

4.Pollution Control and Ecosystem Protection

- Southern Taiwan Air Quality Improvement
- Soil＆Groundwater Remediation
- Deep Investigation for Law Enforcement：for example sludge check for wastewater treatment practice.

5.Promoting clean and healthy society

- Green consumption and carbon footprint label.
- Toxic chemical control and disaster prevention

- **Without a doubt, EPA Minster Stephen Shen has already made great strides in making Taiwan cleaner and greener, but there is still much to be accomplished for the country to become a "beautiful and low-carbon island."**

- **The Ministry of Environment and Natural Resources will be established on 1 January 2013 to encompass water, land, forest and mineral resource in order to integrate environmental protection and ecological conservation.**

Vice President Wu

- The announcement made by President Ma Ying-Jeou regarding his decision to ask the state-owned CPC Corporation to withdraw its investment in the naphtha cracking complex, known as Kuokuang Petrochemical Project. We anticipate the positive long-term effect of this decision.

The National Environmental Analysis Building

- has a ground area of 36,000 m^2.
- consists of a modernized Roman style courtyard and a central office building surrounded by laboratories on two wings.
- The EAL is divided into five divisions with total 120 employees and supervises about 100 commercial labs.

Instruments and Capabilities

$PM_{2.5}$ & $PM_{0.1}$ measurement — **Ambient $PM_{2.5}$（$\mu g/m^3$）**

Mobile Lab — **Real-time, On-road Air Quality Monitoring**

Continuous monitoring for Hg — **Gaseous Hg in ambient ppb level**

PTR-MS（Proton Transfers or reaction mass Spectrometry） — **Real-time online VOCs SVOCs in air ppb level**

LC-MS-MS（API2000 and API 3000） — **algae toxins, environ. hormones, pesticides, pharmaceuticals ppb~ppt level**

Two-dimensional | **SVOCs, ppb level**

GC-TOF-MS | **Analysis of stable isotope**

GC-IRMS | **ratio of C. N.H ppm level**

HRGC/HRMS | **Dioxin, Dioxin-like PCBs ＆pops, ppt level**

ICP-MS | **trace metals and elements ppb~ppt level**
Can be conjugated with HPLC for Cr and As, with GC for Sn Compounds

Main projects in 2011~2012：

- **Wetland survey：water, sediment and biological quality study**
- **Passive sampler devices development**

Passive Sampler

- **Greener pretreatment or analytical techniques**
- **Integrate Mobile Lab, PTR-MS and micro-meteorological model to identify air pollution incident on a real-time basis**
- **Bionanotechnology application for biosensor and biochip development.**
- **More information Please find：**
  www.niea.gov.tw/english

Ⅱ. Some Interested Areas of Research by Prof. Roam

1.Nanotechnology

- **Characterization of carbon fractions for atmospheric fine particles and nanoparticles in a highway tunnel （Atmospheric Environ.44（2010）2668-2673）**

  Fine particle（$PM_{2.5}$）and nanoparticle（$PM_{0.1}$）were sampled using Dichotomous sampler and MOUDI, respectively, in Xueshan Tunnel（雪山隧道）, Taiwan. Results showed that the ratios of OC/EC were 1.26 and 0.67 for $PM_{2.5}$and $PM_{0.1}$, the variation was partly owing to the metal catalysis for soot oxidation.

- **Source Characterization and Apportionment of PM_{10}, $PM_{2.5}$, $PM_{0.1}$ Using Positive Matrix Factorization in Shinjung Station, Taiwan., Aerosol and Air Quality Research, 2012.**
- **Positive Sampling Artifacts of Organic Carbon Fractions for Fine Particles and Nanoparticles in a Tunnel Environment, Atmospheric Environment, 54:225-230, 2012 .**

- **Ultrafine particle at three sampling locations in Taiwan（Atmospheric Environ.44（2010）533-540）**

Atmospheric ultrafine particles（Ups or $PM_{0.1}$）were investigated at the roadside of Syuefu road in Hsinchu（學府路）, in the Syueshan highway tunnel in Taipei and in the NTU Experimental Forest in Nantou（台大梅峰森林試驗場）。Based on this study, it is foreseeable that the number concertratin of the SMPS can be converted using the effective density determined by Spencer et. al.（2007）for the real time measurement of the $PM_{0.1}$ concentration.

- **The Influence of Relative Humidity on Nanoparticle Concentration and Particle mass Sistribution Measurements by the MOUDI, Aerosol Science and Technology, 45:496-603, 2011.**

- **Chemical Mass Closure and Chemical Characteristics of Ambient Ultrafine Particles and other PM Fractions. （Aerosol Science and Technology,44,713-723,2010）**

  The OC artifact was studied and quantified using the quartz behind quartz（QBQ）method for all PM fractions, chemical mass closure of $PM_{0.1}$, $PM_{2.5}$ and PM_{10} was calculated and found to be good.

2.Anaerobic process for wastewater

- **A Modified UASB Process Treating Winery Wastewater.（Wat. Sci. Tech 22.9.167-174,1990）**

  Twenty-seven bioreactiors of upflow anaerobic sludgeblanket（UASB）process were constructed and operation well to treat winery wastewater during 1988-1990 in Taiwan. Start-up strategies and kinetics and granule morphology were studied in three UASB systems.

- **A case study of an Automobile Coating Wastewater Treatment Plant by Anaerobic SBR.（The first IAWQ specializd conference on Sequencing Batch Reactor Technology, March 18-20, 1996, Germany）**

  A pilot study showed that 91% of the total COD or 92% of the total BOD could be removed after the anaerobic SBR. The conditions used for the SBR process in this study were：influent COD~11. 200 mg/l BOD~7770 mg/l, hydraulic retention time＝10 days, volume loading＝1.14 kg COD/m3-day.

- **Some Experiences on Anaerobic Some Experiences on Anaerobic Process for Wastewater Treatment.（CICHE-AICHE Symposium on Modern Chemical Engineering Technology, Taipei, Sept. 1986）**

  A pilot scale of 85m3UASB reactor was established for treating citric acid fermentation industrial wastewater.

- **Biological Desulfurization for Anaerobic Effluent.**

  Conversion of sulfate to hydrogen sulfide in the biological anaerobic wastewater treatment system results both toxic and odor problems. Our study utilize photosynthetic sulfur bacteria（PSB）as biocatalyst to remove sulfide from wastewater. Green sulfur bacteria（Chlorobium）was the dominant species in all reactors. Influent total sulfide concentration was about 200 ppm, surface loading rate was 1.0 gTS/m2/day, Light intensity was 500-1500lux, Hydraulic retention time was 0.5 day, and Effluent was less than 1 ppm, which meet National Standard.

- **Extracellular Polymer and Aggregation Rates in UASB Reactors (AICHE, 1986)**

  Extra-cellular polysaccharide ECPs is proposed as an important means for trapping and retaining mixed cultures of anaerobic bacteria into 0.2-1.0mm diameter granules in UASB reactors. Rapid aggregation of bacteria into consortia is necessary to minimize start-up time and obtain high specific bioactivity. Varying substrate and substrate loading resulting in overproduction of ECPs (10-30 times of those traditional cycles) was found and rapid granulation rate was shown to correlate with ECPs concentration in cells.

- **Mechanics of Bacterial Granulation in UASB Reactors (AICHE, 1986)**

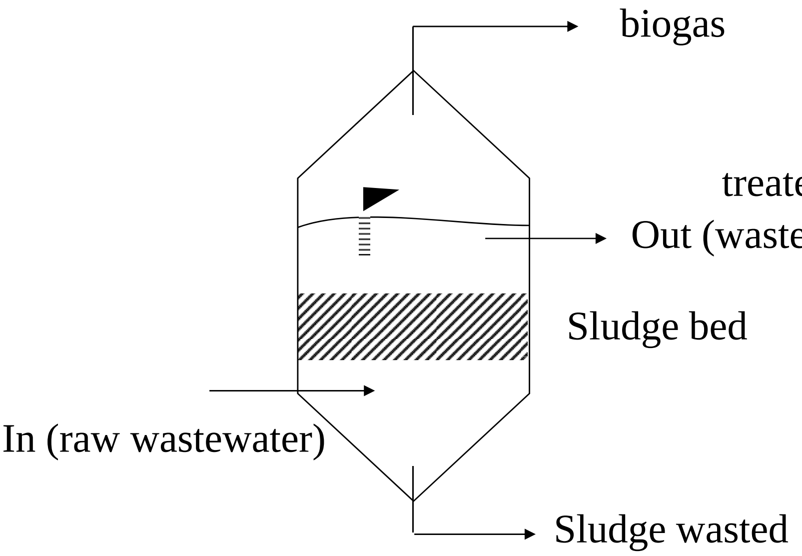
  Possible mechanisms including polymer controlled growth and diffusion and reaction linked growth were discussed. A model of growth of anaerobic microbial aggregates to visible granule structures was described for UASB reactor converting sucrose or acetate feed.

- **Transport Attachment and Aggregation of Colloids in Anaerobic Biofilm and Biofloc Systems. (AICHE, 1987)**

A framework for colloidal material including substrate retention/utilization in anaerobic biofilm and biofloc systems was reviewed in terms of governing steps and important assumptions or parameters to be evaluated and experimental techniques and research needs. Anaerobic organism flocculation, granulation or dispersion is important in its own right and in analogy to the attachment step depends on solution and colloid chemistry, flow regime and other chemical and physical factors, substrate mix and culture type (pure or mixed) in both biofilm and bioblanket reactions.

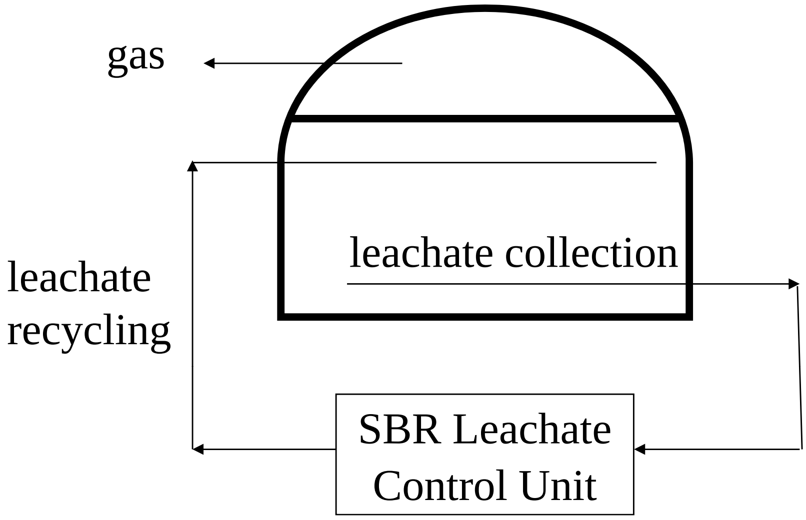
3. Environmental Technology Advancement：

（1）UASB：Upflow Anaerobic Sludge Bed Reactor



high organic loading：
100~200 kg BOD/m^3
low sludge yield：
1~10％ of BODr

(2) New process for Bioreactor Landfill: Leachate (SBR) Initiates Nitrification and Aerobic Oxidation process

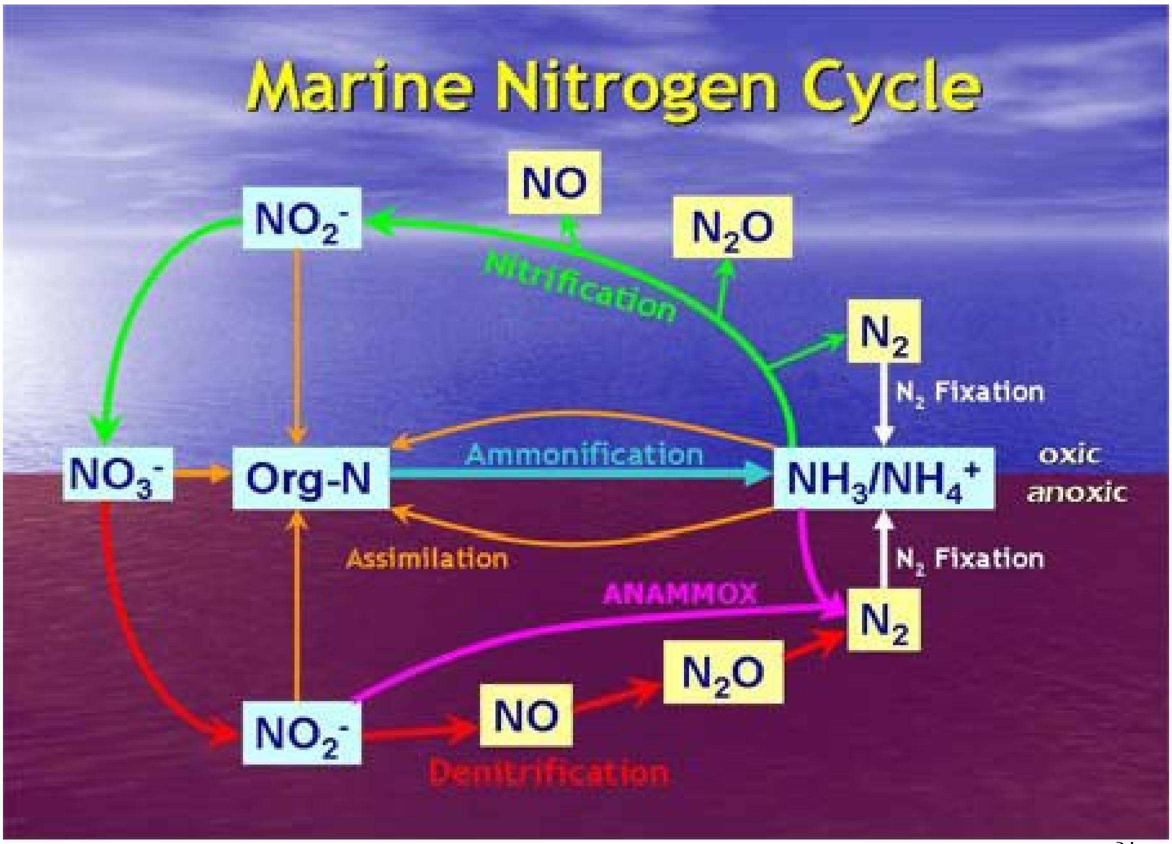


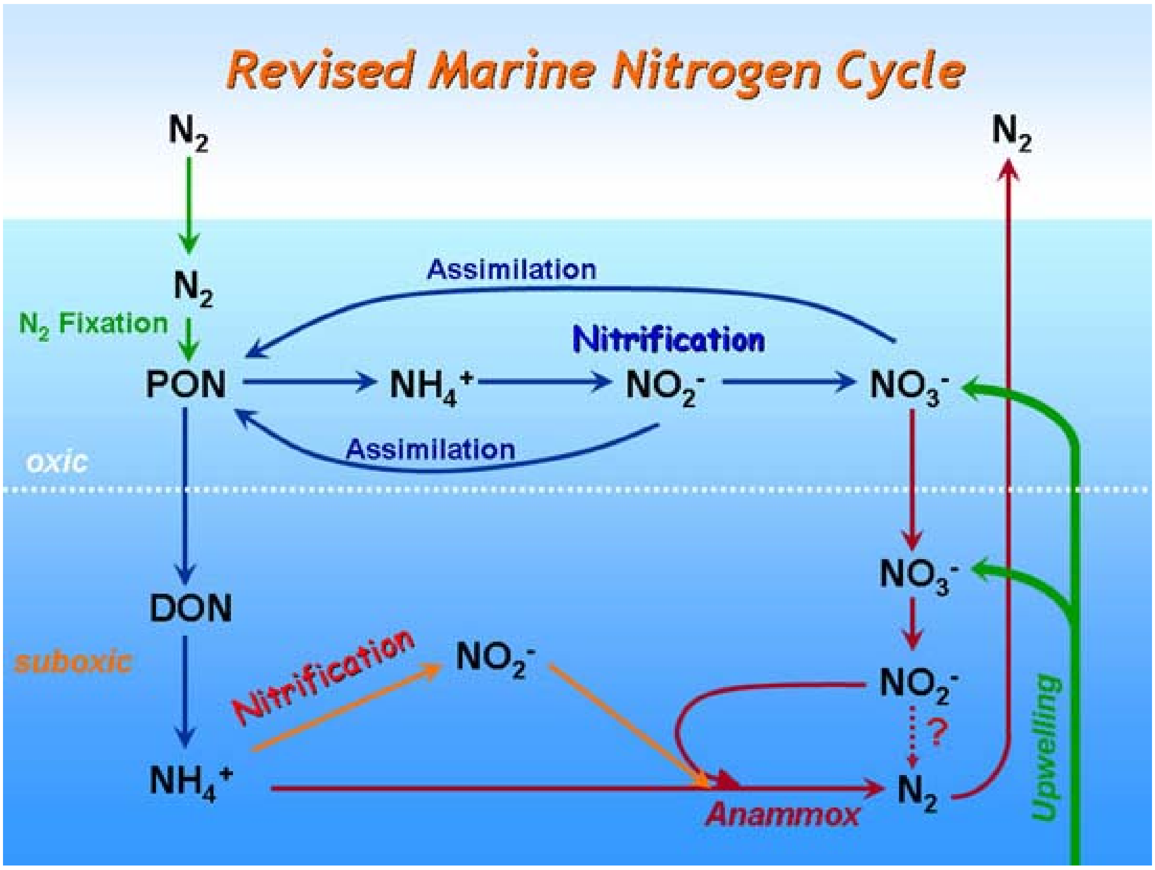
Safer：no air or free O_2 used in the field.
Controllable：dissolved oxygen transferred only by leachate in which O_2 can be controlled quantitatively.

(3) Anammox Process
(Anaerobic Ammonium Oxidation process)
(90% operation costs savings and CO_2 emission cuts, compared conventional nitrification/denitrification.)

$$\underbrace{\underset{①}{NH_4^+} \xrightarrow{+2O} \underset{②}{NO_2^-} \xrightarrow{+O} \underset{③}{NO_3^-}}_{\text{Oxidation or Nitrification}} \underbrace{\xrightarrow{-O} \underset{④}{NO_2^-} \xrightarrow{-2O} \underset{⑤}{N_2}}_{\text{Reduction or Denitrification}}$$

$$NH_4^+ + NO_2^- \longrightarrow N_2 + H_2O$$


Marine Nitrogen Cycle
NO
NO_2^-
N_2O
Nitrification
N_2
N_2 Fixation
NO_3^-
Org-N
Ammonification
NH_3/NH_4^+
oxic
anoxic
Assimilation
N_2 Fixation
ANAMMOX
N_2
N_2O
NO_2^-
NO
Denitrification


Revised Marine Nitrogen Cycle
N_2
N_2
Assimilation
N_2
N_2 Fixation
Nitrification
PON
NH_4^+
NO_2^-
NO_3^-
Assimilation
oxic
NO_3^-
DON
suboxic
Nitrification
NO_2^-
NO_2^-
?
Upwelling
NH_4^+
Anammox
N_2

（4）Targeting DNAPL source zones by surface modifications Fe Nanocompsites.

- TCE/PCE specific gravity
- Behaviors in Saturated Porous Media

DNAPL$_S$：Dense Non-Aqueous Phase Liquids, such as TCE, PCE (s.g.＞1.0)

LANAP$_S$：Light NAPL$_S$, such as gasoline, diesel oil (s.g.＜1.0)

- AIPs：Amphiphilic Invertable Polymers

（5）Capacitive Deionization (CD) with Nanotechnology Membrane Technology

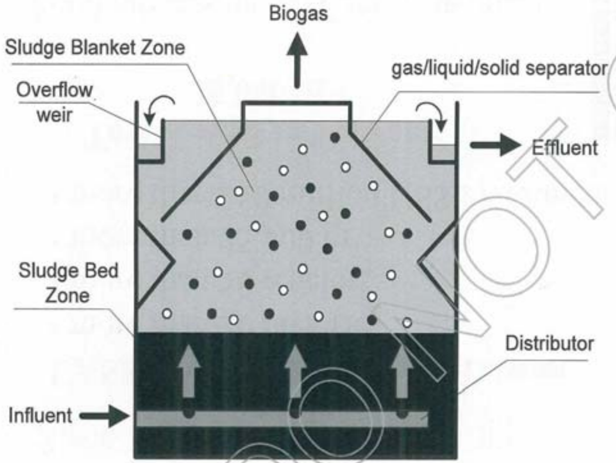
Negative Electrode

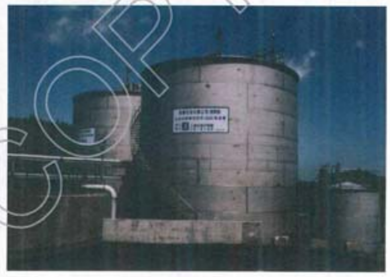
Contaminated Water → Treated Water →

Positive Electrode

(TR3 Energy Inc.)

Upflow Anaerobic Sludge Bed (UASB)





Features
- **Low investment cost (land requirement & construction cost)**
- **Low operating cost (power , chemicals requirement& sludge yield)**
- **Potential energy recovery (methane is usable)**

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UASB Technology Applications

Factory name	Date of installation	Reactor Size (m^3)	Type of Wastewater	Qw.w. (CMD)	COD-in (mg/l)	CODr (%)
Asia Chemical Co.	1988	1,000	Chemical processing	400	9,000	98
Yilan Wine plant, (total 7 plants)	1992	3,000	Fermentation and distillation	60-1,000	4,000-30,000	90
Hualon Toufen Ⅲ	1994	600× 2	Textile industry	1,200	5,000	90
Hualien distillery	1995	1,300	Distillation	1,300	10,000	90
Hualon **Malaysia** I	1995	600× 2	Textile industry	1,200	5,000	90
Hualon **Malaysia** II	1996	600× 2	Textile industry	1,200	5,000	90
Dahin Co./Chuan Hsing plant	1996	500	Chemical processing	200	8,000	≧70
Taiwan petrochemical	1999	800	Chemical processing	124	12,000	80
Dahin Co.	1999	900	Chemical processing	400	8,000	80
President Enterprises Co. II	2002	900 x 2	Food processing	4,000	2,500	90
Der-Yien Paper Industry	2002	900 x2	Pulp and paper	3,600	7,000	80
Chang Chun Petrochemical II	2003	1,350 x 2	Petrochemical industry	2,000	3,000	≧70
Kinmon distillery	2003	1,000	Distillation	650	3,000	90

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UASB for TFT-LCD wastewater treatment (2004-2006)

Factory name	Comple-tion	Reactor size (m^3)	Type of wastewater	Flowrate (CMD)	COD (mg/L)
Toppoly Optoelectronics	2005	1,760	TFT-LCD (MEA, BDG, TMAH)	1,400	8,000
Chi Mei Optoelectronics II	2005	900	TFT-LCD (MEA, DMSO, TMAH)	1,650	1,000
Chi Mei Optoelectronics I	2006	400	TFT-LCD (MEA, DMSO, TMAH)	650	1,000

Composition of TFT-LCD wastewater

Dimethyl Sulphoxide (DMSO) $[(CH_3)_2SO]$

Monoethanoamine (MEA) $[HOCH_2CH_2NH_2]$

Butyldiglycol (BDG) $[HO(CH_2)_2O(CH_2)_2O(CH_2)_3CH_3]$

Tetramethylammonium Hydroxide (TMAH) $[(CH_3)_4N^+ \bullet OH^-]$

Detergent

5

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Know-how and Patents Contribution：

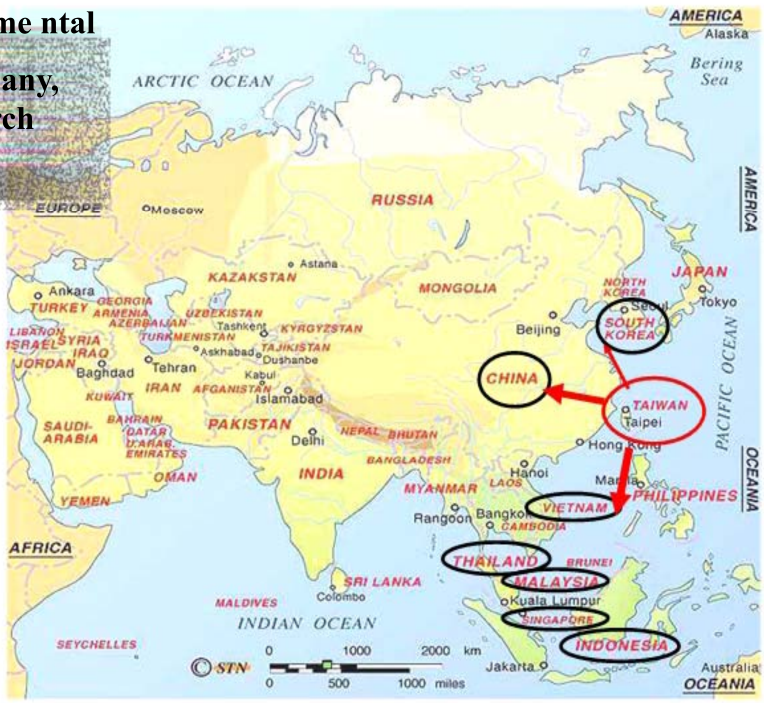
- **Gwo-Dong Roam, Mechanisms of Anaerobic Microbial Aggregation, Ph.D Dissertation, Northwestern University, USA, 1988.**
- **Extracellular Polymer（ECP）and Aggregation Rates in UASB.**
- **Starvation Start-up Operation Mode can reduce the start-up period of time from 3 months to 3 weeks.**

- **UASB process and MBR and FBC processes have been commercialized in hundreds of facilities in various industries worldwise, especially asia.**
- **MBR (membrane-based bioreactor) process:**
  Non-woven fiber MBR is the ITRI's solution to overcome the membrane fouling and the flux.
- **FBC (fluidized bed crystallization) process:**
  Distributor design operation control practices.

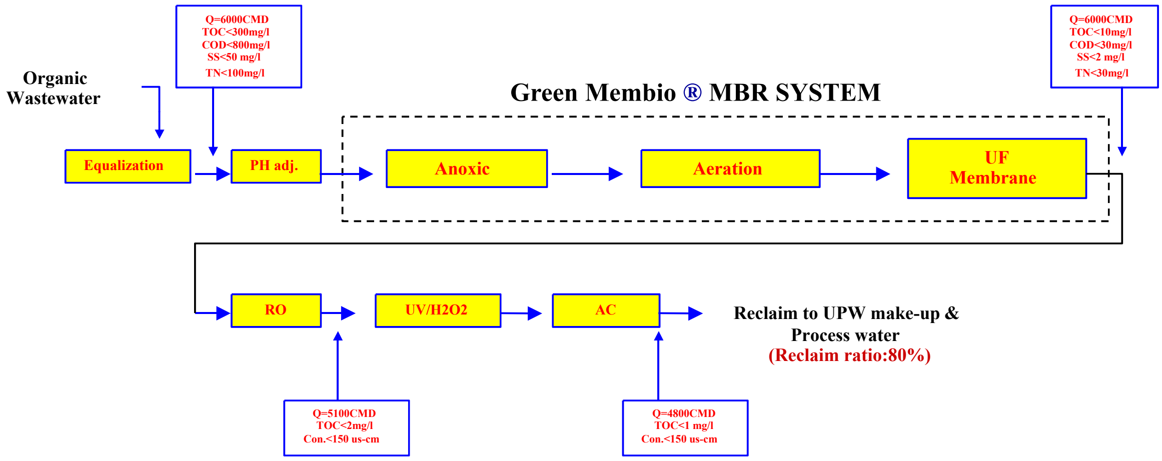
Target market of ITRI- Asia

Partners: Environme ntal

Engineering company, University, Research Institute

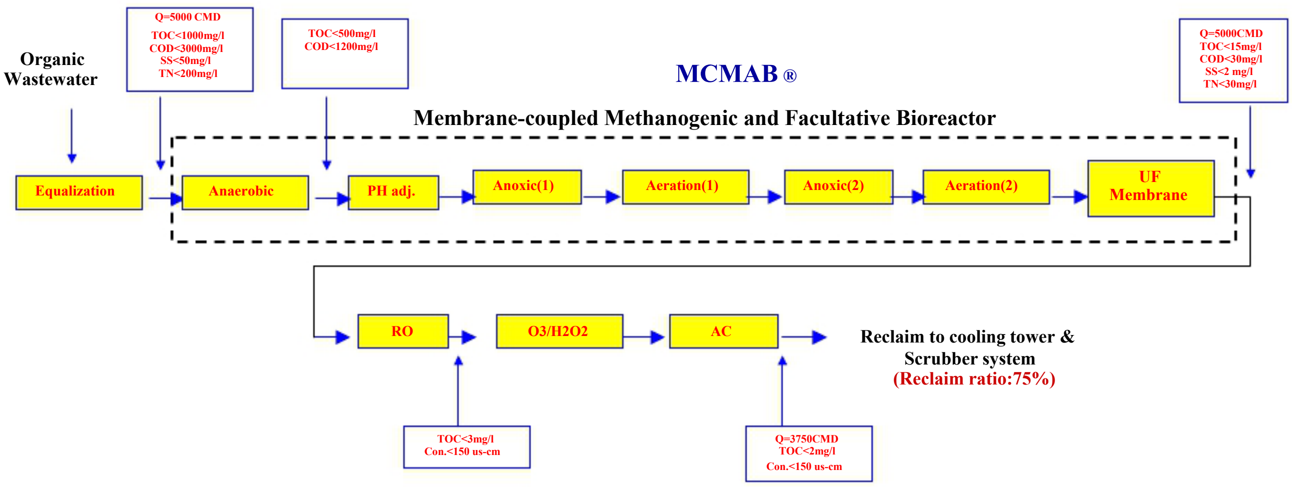


Low Organic Wastewater Treatment and Reclamation Plant(6000CMD)



Process flow for the LOWTRP

High Organic Wastewater Treatment and Reclamation Plant (5000CMD)



Process flow for the HOWTRP

4.Advanced Oxidation Process (AOP)

- **Factors affecting the photo-catalytic degradation of dichlorvos over titanium dioxide supported on glass. (J. Photochem. Photobiol. A: Chem 76 (1993) 103-110)**

The photocatalytic degradation of organophosphorus insecticide, dichlorvos, on glass-supported TiO_2 was investigated. The activated energy for the photocatalytic degradation of dichlorvos is 28.4 KJ/mol. The initial quantum yield is 2.67% ,dichlorvos (2.2- Dichtorovinyl dimethyl phosphate, $(CH3O)_2POOCHCCl_2$) can produce phosphate – contains and chloride-containing intermediates.

- **Microtox Bioassay of Photodegradation products from Photocatalytic Oxidation of Pesticides. (Chemosphere, 27. 9, (637-1674, 1993)**

Dichlorvos (an insecticide), 2.4-D (a herbicide) and propoxur (an insecticide) were used as the model compounds in these experiments. The degradation pathway and toxicity of pesticides treated in photocatalytic process are PH depentent.

- **Application of photocatalytic Technology to the Destruction of Hazanlous wastes.**

  The model compounds, dichiorvos, propour and 2.4-D, were used in this experiments. Results showed that the photocatalytic system is actually effective in mineralizing the pesticide. A mark increase in the mineralization rate under acid condition was observed. The kinetics of these reactions followed Langmuir mode.

5.Colloid chemistry

- **Chemelectrophoresic Enhanced Deposition from Aqueous Suspension (AICHE, 1980)**

  Theoretical analysis of chemiphoresis in packed beds, with cocurrent ion exchange, suggests moderate to large enhance of collection for micro to submicron (Brownian) particles, respectively. Experiments performed with polystyrene latex collection on strongly basic anion resin beads under conditions where London and Brownian collection are of comparable magnitude found collection enhanced in the order of the duffusion potential of the exchanging ion couple, eg; chloride-sulfate and acetate-sulfate, but total collection was less than expected by theory.

- **Chemelectrophoresic Enhanced Deposition from Aqueous Suspension onto Ion Exchange Resins (Proc. 7th conf. on Wastewater Treatment Technology, Taiwan, 1982)**

  Experiment in the convective diffusion range showed much more dramatic enhancement of collection. Results suggested that chemiphoresis may play a major role in enhanced collection of submicron particles in conjuctive ion exchange process. Some potential applications in industrial and water purification technology were discussed.

6.Risk Assessment

- **Priority Setting of Environmental Risks: How People View Environmental Risks (The 1st conference on Comparative Risk Assessment Denver, 1992)**

  The objective of this study was to identify the expert's opinion of the 23 environmental issues proposed by USEPA's Unfinished Business Report in 1986. A specifically designed questionaire was employed to explore what the experts concern: We found that automotive vehicle exhaust was the most concerned problem, worker exposure to chemicals almost stood at one of the top four high risks except the economic impact.

Ⅲ. Roadmap and Case Studies of Green Chemistry

- External Drivers:Two-track systems
- Convergent Technology:accelerators
- Case studies

Driven by Environmental Consciousness / Policy

Pollution Control	Cradle to Grave Policy	Pollution Prevention	Cradle to Cradle Policy	Sustainable Development
The-end-of-the-pipe Technology	Waste Minimization Technology	Source Reduction Technology	Clean Production	Renewable Energy R/D
1960's	*1970's*	*1980's*	*1990's*	*2000's*

Driven by Green Chemistry / Technology

Driven by Environmental Consciousness / Policy

Climate Change
Mitigation & Adaptation

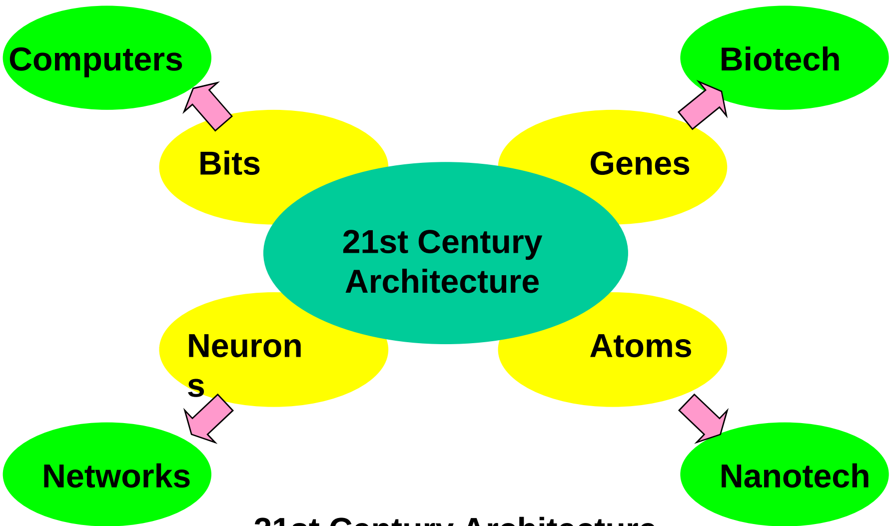
2025 Millennium Development Goals
Pursuing Human Welfare

Four O's Convergent Technology
(nano-bio-info-cogno)

Clean Energy Alternatives
Carbon Neutral Technology

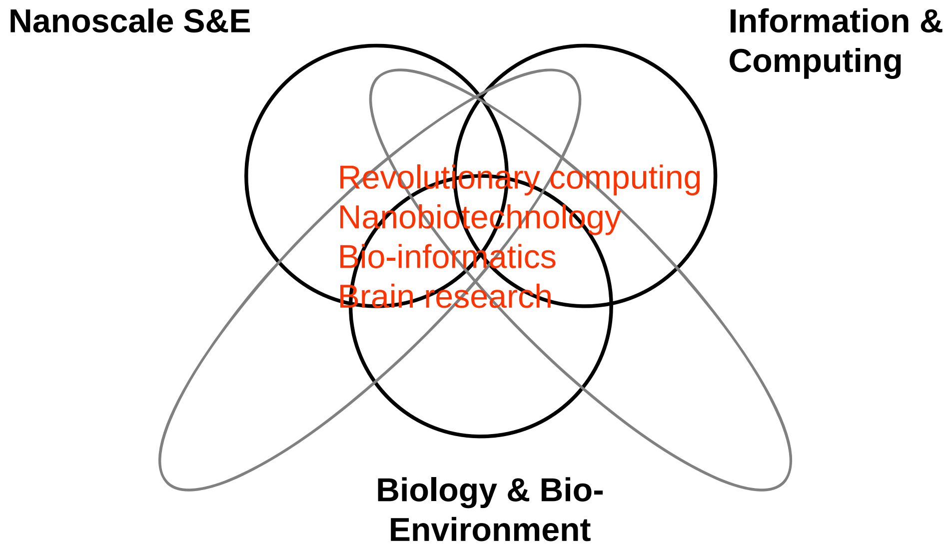
2012 (● We are here) 2015 2030

Driven by Green Chemistry / Technology



21st Century Architecture

Cited from M.C. Roco, W.S. Bainbridge, (2002), "Converging Technology for Improving Human Performance", pp71, Kluwer Academic Publishers.



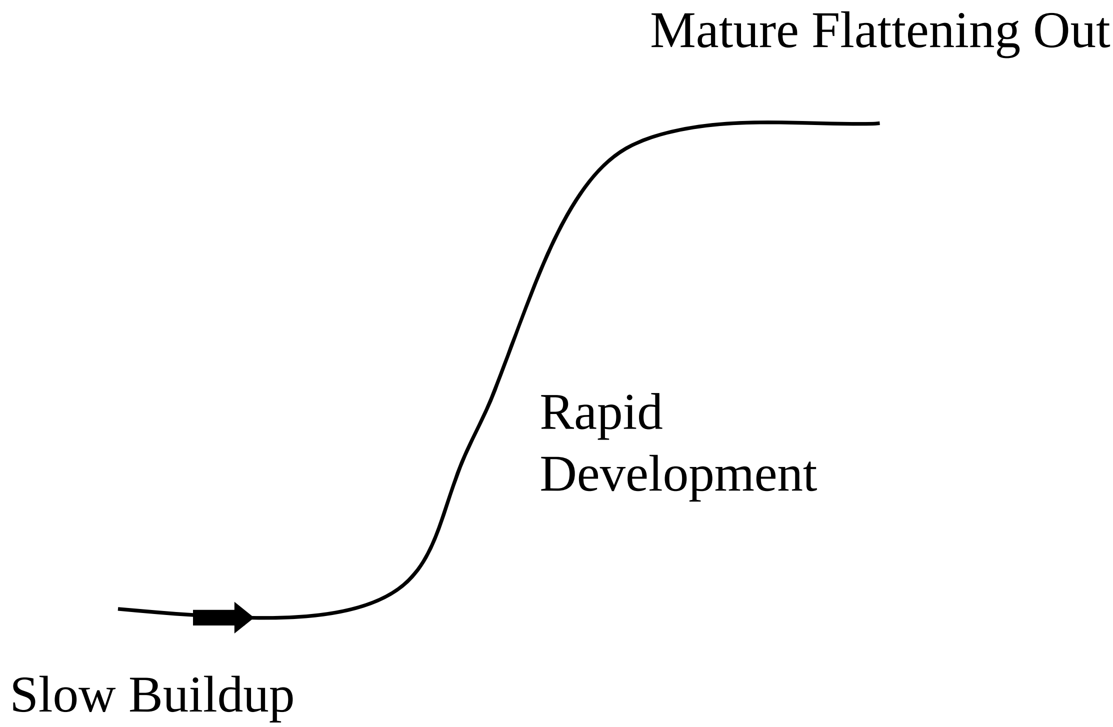
Coherence and synergism at the confluence of NBIC science and engineering streams.

Cited from M.C. Roco, W.S. Bainbridge, (2002), "Converging Technology for Improving Human Performance", pp81, Kluwer Academic Publishers.

The S-curve of Technology Change

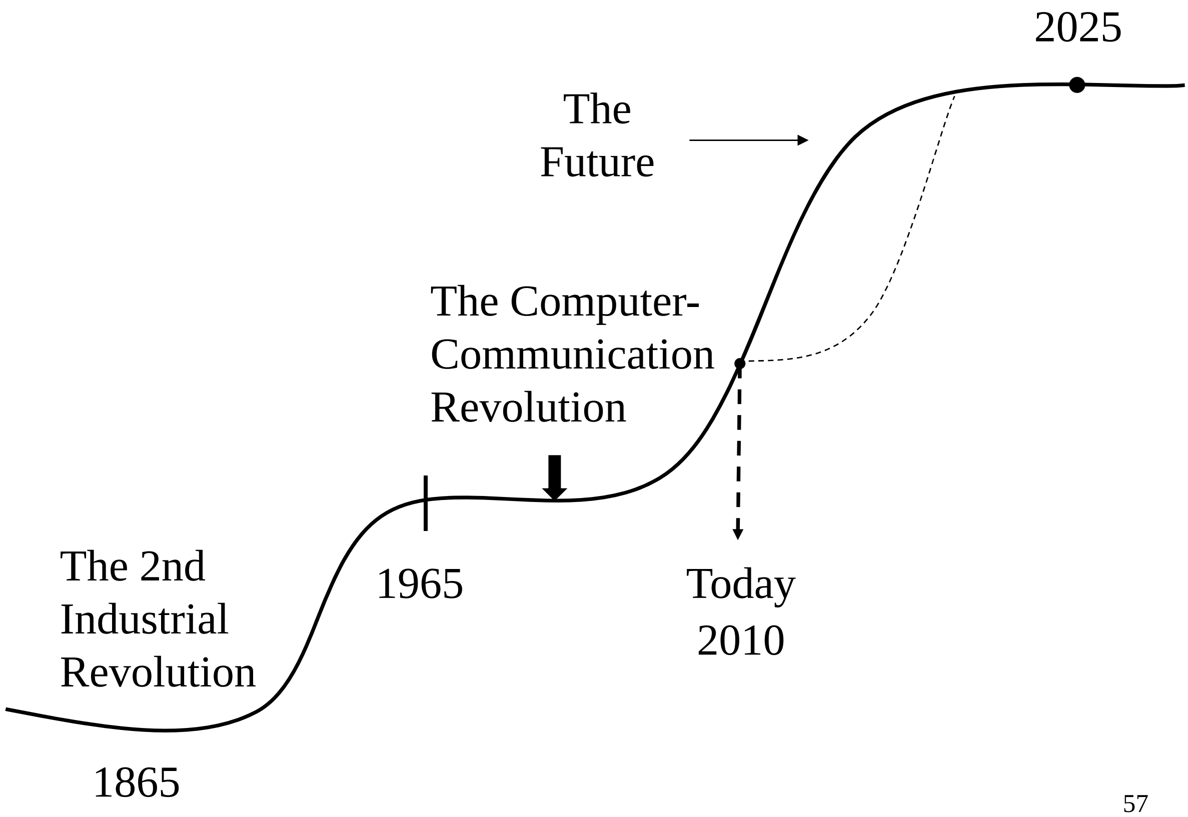
The communication-computer revolution and the earlier Industrial Revolution are both examples of the concept of an S-curve. The S-curve depicts the evolution of technology change. Science and technology begin to accelerate slowly, and then as knowledge and experience accumulates, they grow much more rapidly.

An overall S-curve is made up of thousands of smaller breakthroughs that create many small S-curve of technology growth.



The Two S-curves of the Age of Transitions

We are starting to live through two patterns of change. The first is the computer and communication revolution. The second, only now beginning to rise, is the combination of nano-bio-info revolution(2010-2025). These two S- curves will overlap. It is the overlapping period that we are just beginning to enter.



$$1.\ H_2 + O_2 \xrightarrow[\text{(4nm palladium - platinum)}]{\text{NxCat}^{\text{TM}}} H_2O_2$$

Direct Synthesis of Hydrogen Peroxide by Selective Nanocatalyst Technology

(Headwaters Technology Innovation / 2008 Presidential Green Chemistry Challenge Greener Reaction Conditions Award)

Innovation and Benefits: Hydrogen peroxide is an environmentally friendly alternative to chlorine and chlorine-containing bleaches and oxidants. It is expensive, however, and its current manufacturing process involves the use of hazardous chemicals. Headwaters Technology Innovation (HTI) developed an advanced metal catalyst that makes hydrogen peroxide directly from hydrogen and oxygen, eliminates the use of hazardous chemicals, and produces water as the only byproduct. HTI has demonstrated their new technology and is partnering with Degussa AG to build plants to produce hydrogen peroxide.

$$1.\ H_2 + O_2 \xrightarrow[\text{(4nm palladium - platinum)}]{N_xCat^{TM}} H_2O_2$$

This breakthrough technology, called NxCat™, is a palladium-platinum catalyst that eliminates all the hazardous reaction conditions and chemicals of the existing process, along with its undesirable byproducts. It produces H_2O_2 more efficiently, cutting both energy use and costs. It uses innocuous, renewable feedstocks and generates no toxic waste.

NxCat™ catalysts work because of their precisely controlled surface morphology. HTI has engineered a set of molecular templates and substrates that maintain control of the catalyst' s crystal structure, particle size, composition, dispersion, and stability. This catalyst has a uniform 4-nanometer feature size that safely enables a high rate of production with a hydrogen gas concentration below 4 percent in air (i.e., below the flammability limit of hydrogen). It also maximizes the selectivity for H_2O_2 up to 100 percent.

Maximize atom economy：Design synthesis so that the final product contains the maximum proportion of the starting materials. There should be few, if any, wasted atoms.

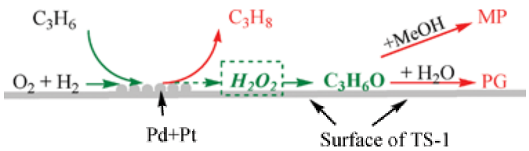
$$\text{Atom Economy} = \frac{\text{m.w.of product} \times 100\%}{\Sigma\text{（m.w.of reagent）}}$$

2. $C_3H_6 + H_2O_2 \longrightarrow C_3H_6O$?

One-pot green synthesis of propylene oxide using *in situ* generated hydrogen peroxide in carbon dioxide

(Qunlai Chen and Eric J. Beckman / Application of 2008 Presidential Green Chemistry Challenge Greener Reaction Conditions Award)

In the one-pot green synthesis of propylene oxide using *in situ* generated hydrogen peroxide, a propylene oxide yield of 23% with 82% selectivity was achieved over a (0.2%Pd + 0.02%Pt)/TS-1 catalyst by using compressed (supercritical or liquid) carbon dioxide as the solvent and small amounts of water and methanol as co-solvents. The addition of an inhibitor effectively suppressed a number of common side-reactions, including the hydrogenation of propylene, the hydrolysis of propylene oxide and the reaction between propylene oxide and methanol. This suppression effect is due to the interaction between the inhibitor and TS-1 leading to the neutralization of its surface acidity.



3. Alkali Metals + nanoscale porous metal oxides → safer materials

New Stabilized Alkali Metals for Safer, Sustainable Syntheses

(SiGNa Chemistry, Inc. / 2008 Presidential Green Chemistry Challenge Small Business Award)

Innovation and Benefits: Alkali metals, such as sodium and lithium, are powerful tools in synthetic chemistry because they are highly reactive. Their reactivity also makes them both flammable and explosive, however, unless they are handled very carefully. SiGNa Chemistry developed a way to stabilize these metals by encapsulating them within porous, sand-like powders, while maintaining their usefulness in synthetic reactions. The stabilized metals are much safer to store, transport, and handle. They may also be useful for removing sulfur from fuels, producing hydrogen, and remediating a variety of hazardous wastes.

3. Alkali Metals + nanoscale porous metal oxides → safer materials

Beyond greening conventional chemical syntheses, SiGNa's materials enable the development of entirely new areas of chemistry. In clean-energy applications, the company's stabilized alkali metals safely produce record levels of pure hydrogen gas for the nascent fuel cell sector. With yield levels that already exceed the Department of Energy's targets for 2015, SiGNa's materials constitute the most effective means for processing water into hydrogen. SiGNa's materials also allow alkali metals to be safely applied to environmental remediation of oil contamination and the destruction of PCBs and CFCs.

SiGNa's success in increasing process efficiencies, health and environmental safety, and entirely new chemical technologies has helped it attract more than 50 major global pharmaceutical, chemical, and energy companies as customers.

4. Various Pollutants + custom made SAMMS™ Nano Products → Qualified Effluent / Air

Development and Commercial Application of SAMMS™, a Novel Adsorbent for Reducing Mercury and Other Toxic Heavy Metals

(Steward Environmental Solutions, LLC & Pacific Northwest National Lab. / 2008 Presidential Green Chemistry Challenge Nomination)

SAMMS™ (self-assembled monolayers on mesoporous silica) was developed and commercialized to adsorb toxic metals such as mercury and lead. SAMMS™ replaces commonly used adsorbents such as activated carbon and ion exchange resins whose manufacture and use are less environmentally friendly. SAMMS™ is a nanoporous adsorbent that forms strong chemical bonds with the target toxic material. It provides superior adsorption capacity and cost economics; it also reduces the volume of hazardous waste. Compared to activated carbon, SAMMS™ can reduce the volume of adsorbent waste by 30-fold.

4. Various Pollutants + custom made SAMMS™ Nano Products → Qualified Effluent / Air

The original functionalization of SAMMS™ used toluene as the solvent. The resulting waste stream included water, methanol, toluene, and traces of mercaptan. It is impractical to separate the components of this mixture; therefore, it was usually disposed of as hazardous waste. This process was improved by substituting a green solvent, supercritical carbon dioxide (sc CO_2), which allows complete silane deposition. With this patented process, SAMMS™ manufacturing is faster and more efficient. The scCO_2 process also results in a higher-quality, defect-free silane monolayer with no residual silane in solution. When the reaction is complete, the only byproduct is the alcohol from the hydrolysis of the alkoxysilane. The CO_2 and the alcohol are readily separated and captured for recycling, eliminating the waste stream in the traditional synthesis. The combination of a green manufacturing process for SAMMS™ and the superior adsorption characteristics of SAMMS™ materials results in a long-term reduction in release of toxic metals into the environment.

5. Waste + Gasification of Syngas + Biotechnology → Coskata Biofuel

(Biofuels : Cellulose Success / Scientific American, 2008)

One promising biofuel procedure that avoids the complex enzymatic chemistry to break down cellulose is now being explored by Coskata in Warrenville, Ill., a firm launched in 2006 by high-profile investors and entrepreneurs (General Motors recently took a minority stake in it as well). In the Coskata operation, a conventional gasification system will use heat to turn various feedstocks into a mixture of carbon monoxide and hydrogen called syngas. The ability to handle multiple plant feedstocks would boost the flexibility of the overall process because each region in the country has access to certain feedstocks but not others.

5. Waste + Gasification of Syngas+ Biotechnology → Coskata Biofuel

The group focused on five promising strains of ethanol-excreting bacteria that Ralph Tanner, a microbiologist at the University of Oklahoma, had discovered years before in the oxygen-free sediments of a swamp. These anaerobic bugs make ethanol by voraciously consuming syngas.

Coskata suggests that in an optimal setting we could get 90 percent of the energy value of the gases into our fuel. Coskata researchers estimate that their commercialized process could deliver ethanol at under $1 per gallon less than half of today's $2-per-gallon wholesale price.

6. Waste + Gasification of Syngas+ Biotechnology → Coskata Biofuel

The input-output "energy balance" of the Coskata process can produce 7.7 times as much energy in the end product as it takes to make it.

Coskata plans to construct a 40,000-gallon-a-year pilot plant near the GM test track in Milford, Mich., by the end of 2008 and hopes to build a full-scale,100-million-gallon-a-year plant by 2011.

Top Chemical Opportunities from Carbohydrates
（Green Chem.2010,12,539-554）

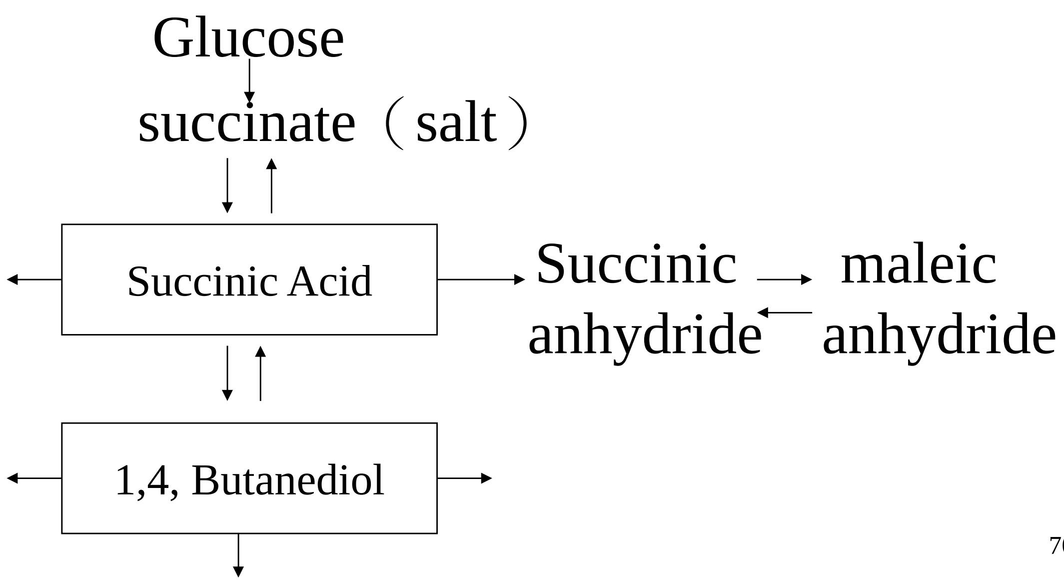
DOE（USA, 2004）

Succinic fumaric
＆malic Acid
2,5-Furandicarboxylic
acid（FDCA）

Bozell＆Peterson（2010）

Ethanol
Furans（FDCA,…）
Lactic Acid
Succinic Acid

Succinic Acid as C-4 Building Block
（Green Chemical, 2009,11,13-26）



- Integrated Production and Downstream Applications of Biobased Succinic Acid

（2011 Us Presidential Green Chemistry Award）

（BioAmber, Inc）（Small Business Award）

- Production of High-Volume Chemicals from Renewable Feedstocks at Lower Cost：1,4-Butanediol（BDO）

（2011 Us Presidential Green Chemistry Award）

（Genomatica）（Greener Synthetic Pathways Award）