A LCA Approach for Making Greener Semiconductor Products

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Current Environmental Situation

The semiconductor industry is a relatively clean industry.

The entire electronic equipment industry (semiconductor or otherwise) in 2000 accounted for only **35 million pounds** of total releases. This is less than the total of the **TWO largest electric utility facilities in the US (roughly 40 million pounds combined)**.

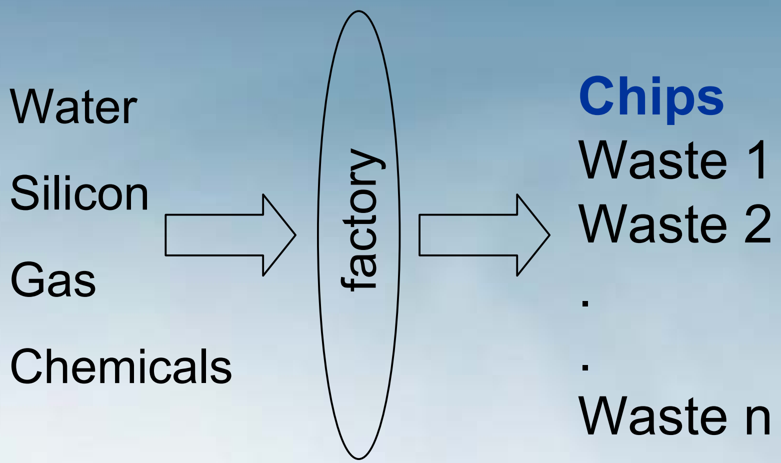
In Arizona the semiconductor industry is responsible for roughly 3% of releases from the entire electric utility and electronic equipment manufacturing facilities categories.

Current Situation (View from the Outside)

"Chip making is sometimes called a 'clean industry' because of the images of technicians in white lab suits working in ultra-clean rooms with shiny pristine silicon wafers. But it is estimated that on the average day of operations at a chip-making plant four million gallons of wastewater are produced, and thousands of gallons of corrosive hazardous materials, like hydrochloric and sulfuric acid, are used. However, there have been few instances of hazardous spills."

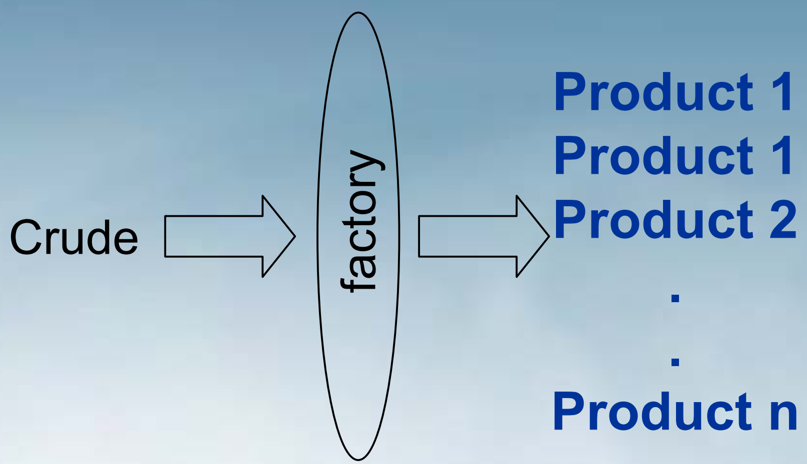
source: SpaceDaily, Agence France-Presse

Production Model



However, in semiconductor manufacturing, there is but one product, with a large number incoming material streams and outgoing waste streams.

Production Model Compared to Petroleum



For example, in **petroleum manufacturing**, almost all of the incoming raw material finds its way into some product. There is little waste.

The semiconductor manufacturing industry must find ways to reduce the amount of raw materials used, while also finding uses for the effluent materials whose purity is no longer acceptable for chip manufacturing.

Current Analysis Tools

Although we are "clean", are we sustainable?

Different sustainability measures:

- Target Method from Agere/NJIT.
- EcoIndicator95.

No consensus yet on how to measure sustainability as defined by the Brundtland report.

Current Analysis Tools

Preliminary studies from NJIT show that silicon wafer manufacturing is very far from being sustainable according to the Target Method.

Therefore:

We need to be proactive in developing sound policies to more toward sustainability so the industry can survive future periods of resource depletion.

We also need to proactively shift public perception of our industry through publicizing our efforts at becoming even cleaner (although we are "clean" already!)

Problems and Opportunities

Rapid

Technology Change

+

Rapid Growth

→

Need for:

- Proactive approach
- Anticipating problems
- Solving problems
- Avoiding problems
- Pre-competitive cooperation

Elements of ESH

What are the elements of ESH conscious design?

Optimize for global optimum for environment, health, safety, and economics

Design plant for future decommissioning

Design products for ease in recycling

Design processes for robustness and ease in changing to more environmentally benign formulations

LCA: Details and How to Carry It Out

LCA is an analytic tool for quantifying the environmental impacts of all processes used in converting raw materials into a final product. It consists of three parts, life cycle inventory, impact assessment, and life cycle improvement.

Life cycle studies have been used to understand three types of problems:

- ✓ Assessments of single products to learn about their eco-profiles.
- ✓ Comparisons of process routes in the production of substitutable products of processes.
- ✓ Comparisons of alternative ways for delivering a given service or function.

Pros and Cons

An LCA study is not very objective because.

- ✓ LCA is based on a number of assumptions and choices
- ✓ LCA methods are still being developed and refined
- ✓ There will always be uncertainties related to data and methods

However LCA is a good tool because

- ✓ No other analytical tools are available yet
- ✓ An assessment will always be subjective

Strength and Weakness

Good side

- ✓ The whole life cycle (avoid sub-optimisation)!!
- ✓ Conversion to potential environmental impacts!!
- ✓ Compare different I/O on the same scale!!
- ✓ Cleaner products
- ✓ Informed choices
- ✓ Prioritise
- ✓ Strategy - can be integrated in DfE and EMS

Strength and Weakness

Problems with LCA **Cost, time, effort**

- ✓ Here and now
- ✓ Time consuming
- ✓ Data are difficult to collect
- ✓ Difficult to interpret and evaluate
- ✓ Not very transparent
- ✓ Does not pay back here and now

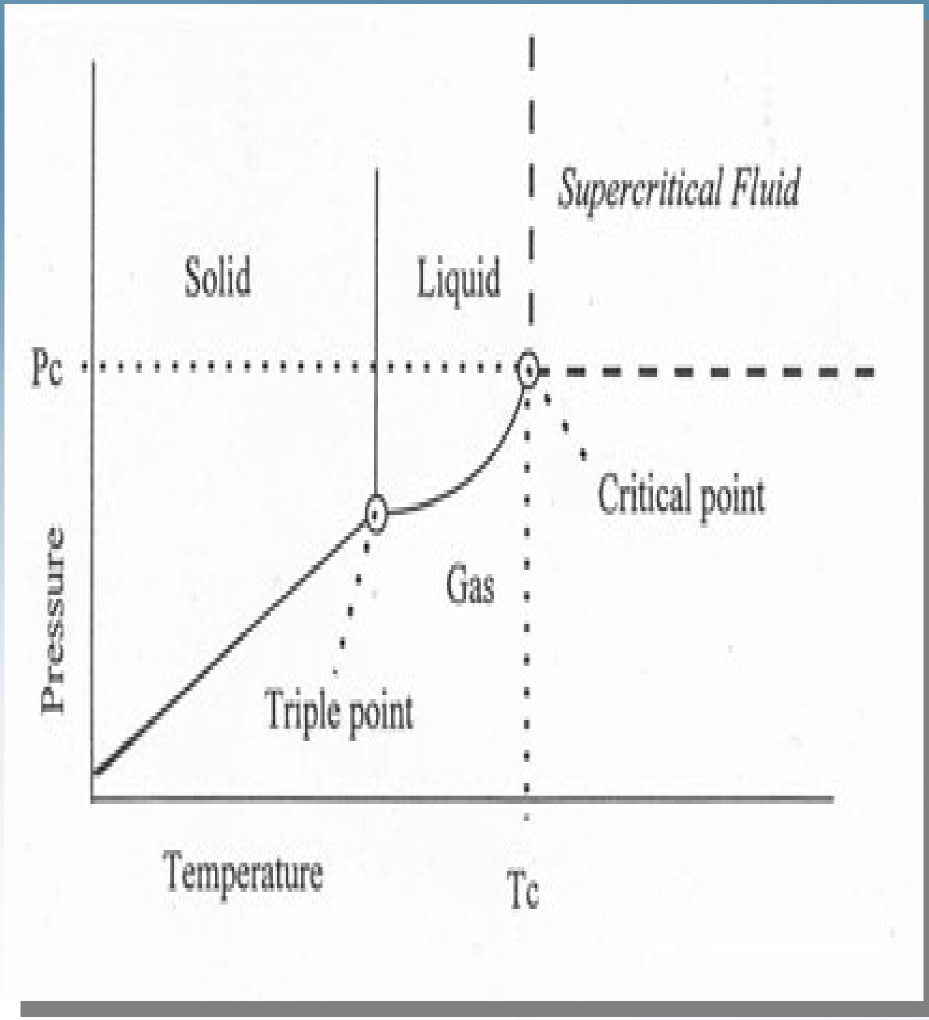
Example of Screening LCA: $scCO_2$

Using carbon dioxide at high temperature and pressures, known as supercritical carbon dioxide ($scCO_2$), in place of hazardous materials, replaces the solvents as well as the tremendous quantities of ultra-pure water that are used to wash those solvents away

Some research that has been underway:

- ✓ GTi manufactures a patented $scCO_2$ drying system
- ✓ The Los Alamos SuperScrub™
- ✓ Thrust B seed project in ERC center: Densified fluid cleaning of semiconductor wafer surfaces

$scCO_2$ Properties



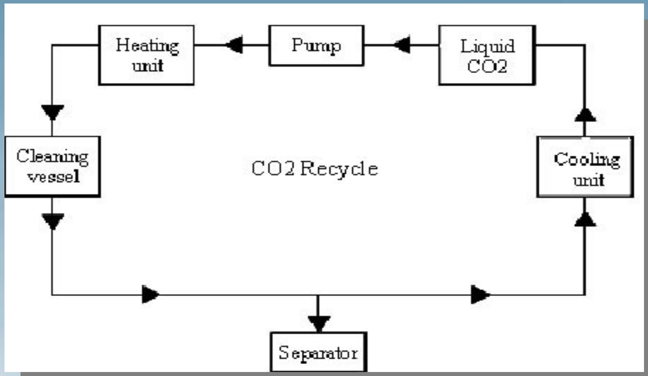
- T_c = 304.19 K, p_c = 7.38 MPa
- Cheap
- Inert
- Physiologically safe
- Ecologically harmless
- Non corrosive
- Non flammable
- High diffusion coefficient
- Low viscosity coefficient

Common Usage of $scCO_2$

Extraction of fragrances

Decaffeinating of coffee, tea

Supercritical CO_2



Remove bitterness from beer

Dry cleaning application

Scope of Boundaries Included

- ✓ **Produce CO_2 (if applicable)**
- ✓ **Collecting CO_2**

Extraction of materials

- ✓ **Processing CO_2 (purify, pressurize, preheat, heat)**

Processing of materials

- ✓ **Using $scCO_2$ on wafer cleaning**

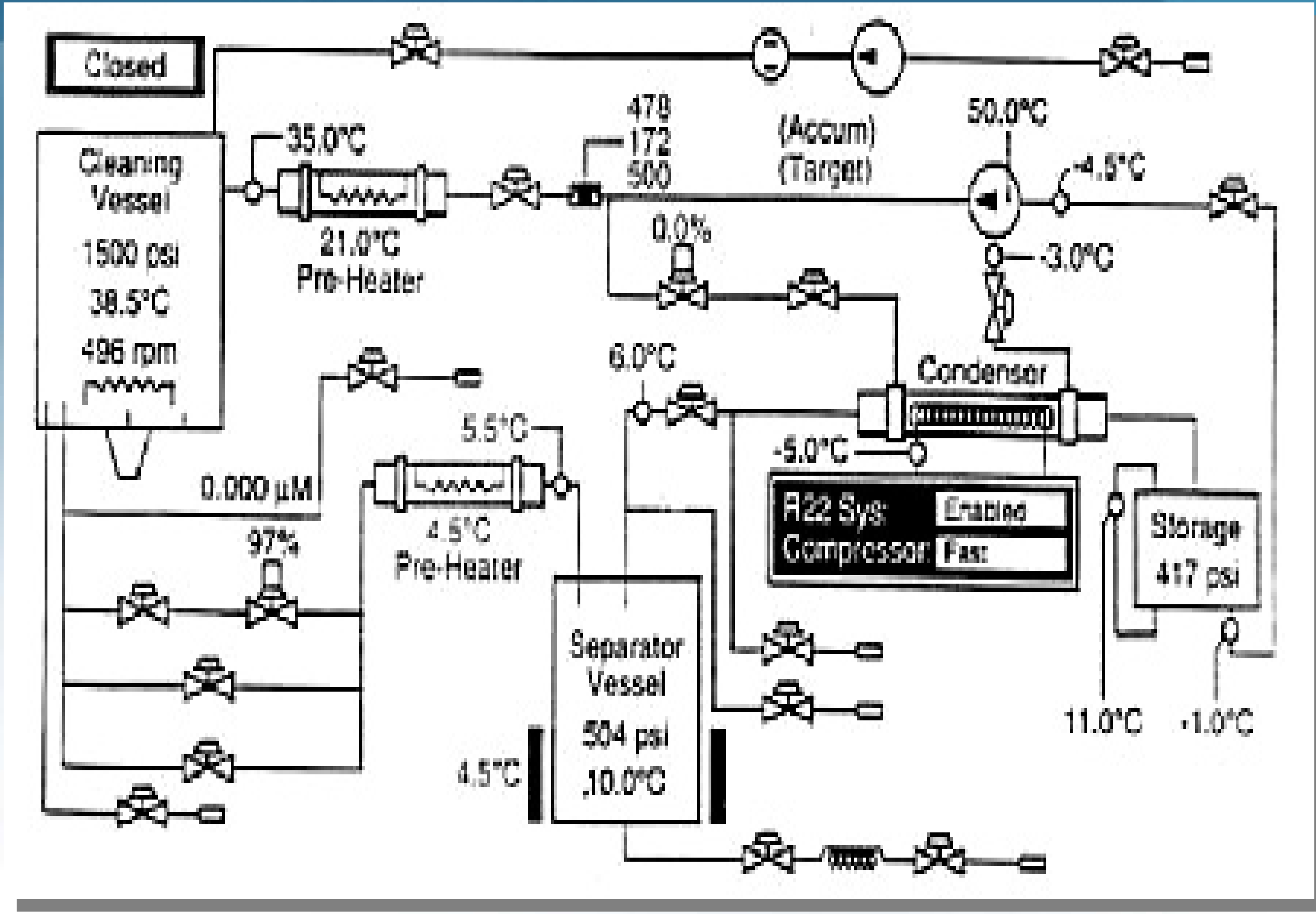
Production and use

- ✓ **Collect CO_2 after use**
- ✓ **Use - reuse**
- ✓ **Disposal - recycling**

Disposal/end of life

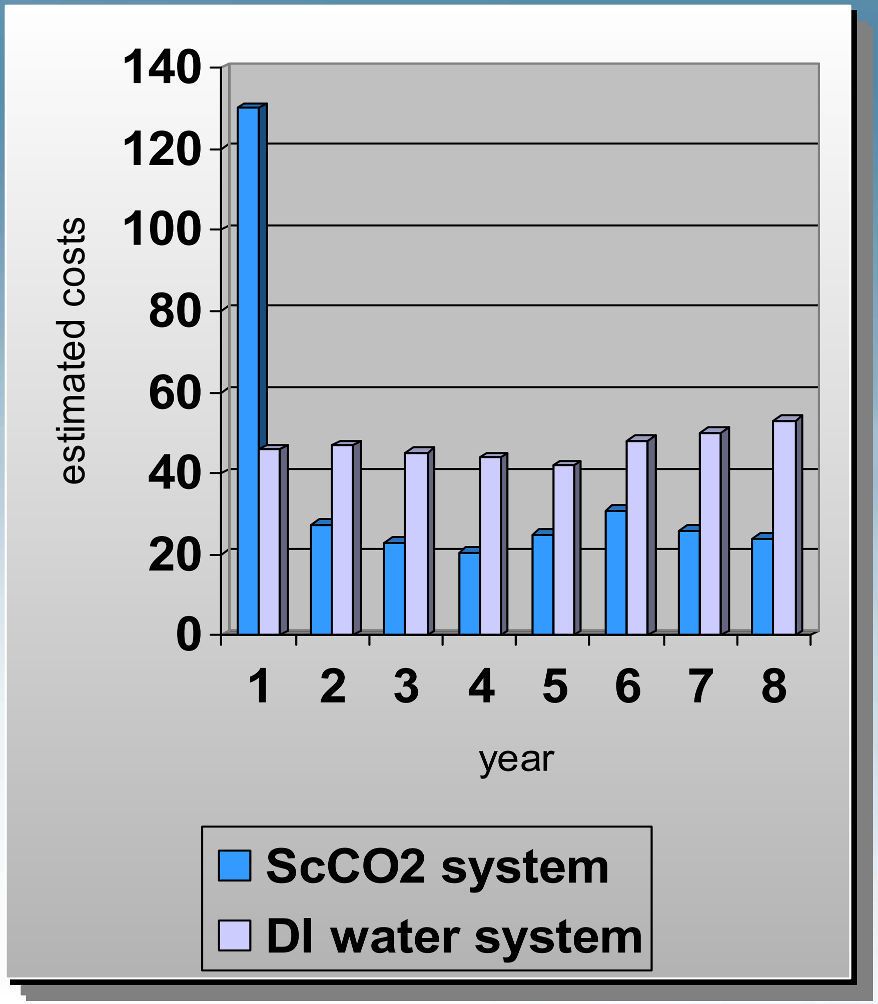
Transportation has been excluded from the boundaries

$scCO_2$ -Los Alamos SuperScrub™ process.



NSF/SRC Engineering Research Center for Environmentally Benign Semiconductor Manufacturing

Expected Results of Economic Aspects



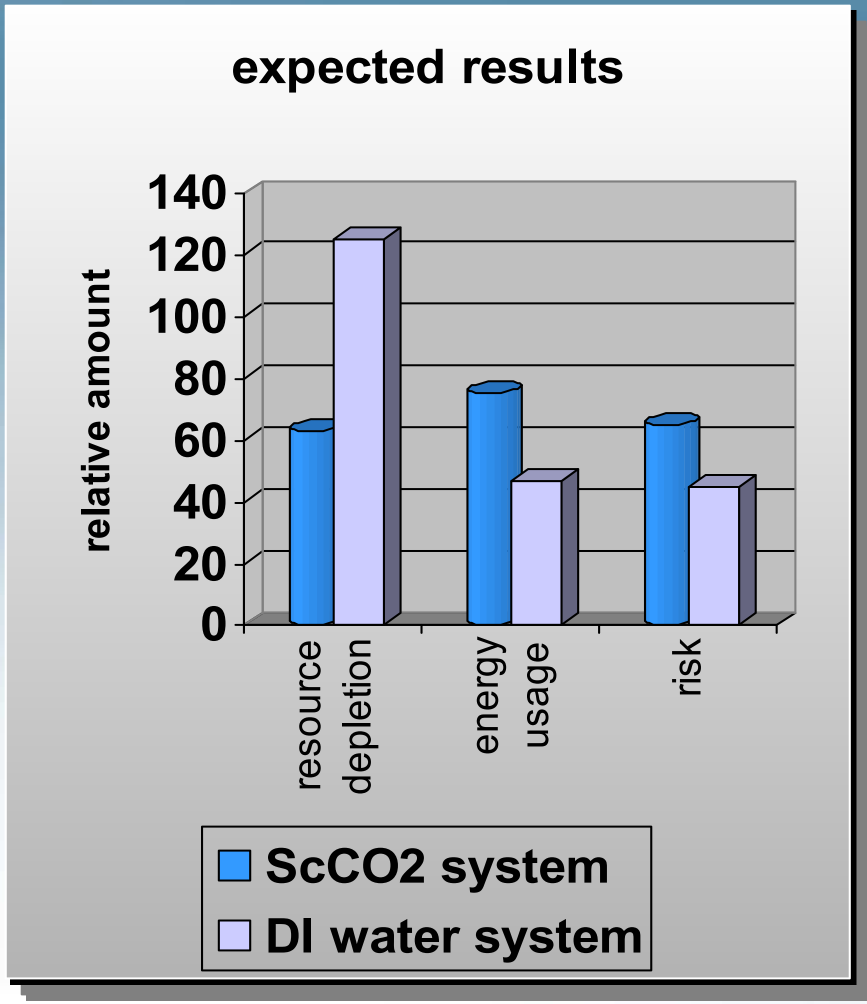
The initial capital costs for $scCO_2$ systems are usually higher than other alternatives by a significant amount.

- ✓ High-pressure cleaning chamber and the valves and instrumentation required for the system.
- ✓ No vendors that mass produce $scco_2$ systems yet.

Cost Components Need to Be Considered

✓ Equipment	✓ Depreciation, moving equipment, rearranging equipment footprint, training
✓ Consumables	✓ Utilities, chemicals, supplies, waste management
✓ Maintenance	✓ Maintenance labor, parts, vendor contracts, vendor training, computer system
✓ Labor	✓ Operators
✓ Support personnel	✓ Higher support personnel, engineering, supervision, contractor labor
✓ Administrative costs	✓ Insurance, taxes, interests

Expected Results of Environmental Aspect



- ✓ DI water uses up many resources
- ✓ $scCO_2$ has to use a lot of energy to operate
- ✓ Because of the high operating pressures of $scCO_2$, we may lower yield or productivity by damaging wafer structures
- ✓ High pressure could induce hazardous problems

The quantifying of each category and underlying categories need future work

Impacts and Results Discussion

Process and equipment developments are making $scCO_2$ more competitive

- ✓ Reducing the requirements for continuous carbon dioxide flow
- ✓ Producing effective cleaning at lower temperatures and pressures
- ✓ The construction of equipment with less expensive materials.
- ✓ $scCO_2$ could be the most environmentally benign based on LCA results even with its high energy costs

A More Complex Process: NF_3 in Cleaning

Use life cycle assessment as a tool for selecting among manufacturing strategies and for selecting within a strategy for improved ESH impact – In chamber cleaning, is use of NF_3 or C_2F_6 “globally” better (cradle to grave)

- ✓ Using LCA can reveal better trade-off decision opportunities
- ✓ All units are involved in the ‘whole picture’ and been investigated, so we can improve ‘sub-optimisation’
- ✓ LCA will look globally at ESH impacts like ozone depletion, resource depletion, toxicity, etc
- ✓ Externalities like transportation, upstream manufacturing activities, and downstream usage all become important

Forms of Fluorine

Fluorine containing species that enter and leave semiconductor Manufacturing processes are normally gases

HF	*an extremely hazardous acid*
NF_3	*a toxic gas*
PFCs, HFCs, CFCs	*multiple hazards, ozone depletion*
NH_4F	*a salt*
BF_3	*a toxic gas*
CF_4	*a colorless, odorless, nonflammable, gas*
SiF_4	*a colorless, corrosive, gas*
SF_6	*a colorless, nontoxic, nonflammable, gas*
WF_6	*a toxic, corrosive, nonflammable liquid*
ArF	*a toxic gas*
KrF	*a toxic gas*
F_2	*a toxic gas*

Trade-offs Between CFC and NF_3

Issues	NF_3	C_2F_6
Cost	Expensive	Less expensive
Impact	Immediate toxicity concerns Long term impact unknown	Green house gas with long impact on environment Strong structure, long life time results in accumulation in atmosphere
Usage	Faster cleaning than C_2F_6 so may reduce some impacts. Produces more F, causing problems in ductwork?	Produces CFCs
Treatment	Use burner box followed by scrubbing. Scrubbers were optimized for CFC control! Problem?!?	Use plasma to break CFCs to harmless and manageable species, then to scrubber. Will produce much CO_2 during treatment.
Manufacturing	Ammonia + fluorine, cupper	Uses non-renewable hydrocarbons, metal-fluorine compounds Complex chemistry with many steps

Data Needed for Complete Evaluation

- ✓ Production methods of NF_3, CFCs
- ✓ Possible mechanism that is happening during the production and usage
- ✓ Input, output inventories data, emission
- ✓ Abatement strategy of NF_3, CFCs
- ✓ Energy usage of producing NF_3, CFCs
- ✓ ESH information of NF_3, CFCs

Difficulties Doing NF_3 Analysis

1. How can proprietary information be used? Information is difficult to share – competitive advantages!

    - ✓Is it possible to create a "black box" approach to aggregate data (UT Austin cluster tool approach).
    - ✓Possibly use slightly outdated "data" from recently discarded processes to provide snap shots of environmental impacts from similar manufacturing steps?

Can the industry create a standard database format for sharing information that is:

- ✓Non-proprietary.
- ✓Still useful?

Difficulties Doing NF_3 Analysis

2. Can we estimate data for LCA to avoid proprietary information sharing?

- ✓Use patents to build representative LCA data? (Too many uncertainties).
- ✓Use a semiconductor industry standard – a "standard wafer" like information furnished by Philips.

Could be used as baseline data for external (academic) use.

Conclusions

- ✓ Life cycle assessment is becoming a useful tool for the semiconductor industry
- ✓ The methodology needs more work to become fast and robust
- ✓ We have to generate a uniform database to facilitate LCA, shortening the time span to meet industry needs

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