Clean Molecular Manufacturing

"No Atom Left Behind"

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Today's dirty manufacturing

- Heavy metals
  - Extraction
  - Manufacturing
  - Disposal
- Processing
  - Coating
  - Trimming
- Imprecise chemistry
 - Sludge

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Mechanical Chemistry

FINGERS
ATOMS

Mechanical Chemistry

➢ Transfer bound molecular fragments

➢ Hydrocarbon tool refreshing (Merkle, 1997)

➢ Need to build **product** with every atom

➢ Proposed bonds are all strong enough to survive at room temperature

➢ Reactions are digital, verifiable

➢ Room-temp atom removal has been done

➢ Mechanical force has been used to:
  ➢ Remove a single silicon atom from a crystal
  ➢ Replace it
  ➢ Bond amino acids

Molecular manufacturing

- **Precise chemistry**
  - Clean manufacturing
- **Light elements**
  - Locally available
  - Easy recycling
- **High-performance products**
  - Strength (1000x)
  - Computation density and efficiency (100,000x)
  - Power density (100,000x)
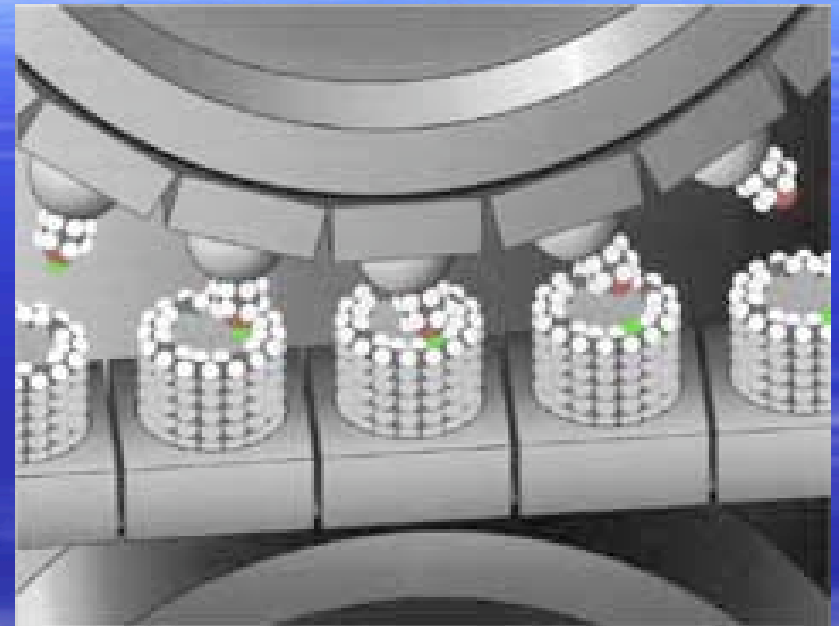
Molecular Mfg. Definition

- **Programmable Chemistry**
  - A few operations, repeated…
- **Molecular Features**
  - High performance
- **Engineered Structures**
  - Easy to design
- **Reliable Operation**
  - Allows automation
- **Autoproductive Manufacture**
  - Exponential manufacturing

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Molecular Mfg. Performance

- Scaling Laws
  - Power density ~ smallness
  - Several kilowatts per cubic millimeter
  - Feature density ~ smallness^3
  - Earth Simulator in a cubic millimeter
- Strength
  - 100 times as strong as steel
  - Another factor of 10 for compression->tension
- A 10-pound airplane, yacht, car…

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Molecular Mfg. Scalability

➢ Scaling Laws, again
  ➢ Operation speed ~ smallness
  ➢ A million operations per second
  ➢ A billion atoms ~ 1/5 micron cube
  ➢ Could be built in ~1 hour by 1 billion-atom robot

➢ These systems, being reliable, could be run in parallel efficiently.

➢ A 10-pound factory, making its duplicate (or anything else) every day…

Solving today's problems…

➢ Fossil fuels → Solar energy

➢ Dirty manufacturing → Replace it

➢ Inefficient infrastructure → Rebuild quickly

➢ Agriculture → Greenhouses

➢ Greenhouse gases → Collect them

➢ Other problems → Monitor them

➢ Small planet → Space access

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…Creating tomorrow's problems

➢ Simple overuse
  ➢ Terraforming
  ➢ Heat pollution
➢ Weapons manufacture
➢ IP control
➢ Social and ethical issues
➢ Etc…

Conclusion

➢ Molecular manufacturing can be as precise and elegant as digital logic.

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