• **ARTIFICIAL PHOTOSYNTHESIS: DIRECT PRODUCTION OF FUELS FROM SUNLIGHT**

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Foresightful Energy Analysis

• We are like tenant farmers chopping down the fence around our house for fuel when we should be using Nature's inexhaustible sources of energy — sun, wind and tide. ...

• “Sunshine is spread out thin and so is electricity. Perhaps they are the same, but we will take that up later. Now the trick was, you see, to concentrate the juice and liberate it as you needed it. The old-fashioned way inaugurated by Jove, of letting it off in a clap of thunder, is dangerous, disconcerting and wasteful. It doesn’t fetch up anywhere. My task was to subdivide the current and use it in a great number of little lights, and to do this I had to store it. And we haven’t really found out how to store it yet and let it off real easy-like and cheap. Why, we have just begun to commence to get ready to find out about electricity. This scheme of combustion to get power makes me sick to think of—it is so wasteful. It is just the old, foolish Prometheus idea, and the father of Prometheus was a baboon.”
Foresightful Energy Analysis

• I'd put my money on the sun and solar energy. What a source of power!

• I hope we don't have to wait until oil and coal run out before we tackle that.
Foresightful Energy Analysis

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• Thomas A. Edison, 1931
Energy Conversion Strategies

Fuels
- CO₂
- Sugar
- H₂O
- O₂

Photosynthesis

Semiconductor/Liquid Junctions
- O₂ → H₂
- H₂O

Electricity
- SC

Photovoltaics
Fuel from Sunlight
Lessons from Photosynthesis

PHOTOSYSTEM I

PHOTOSYSTEM II

RESTORING PHOTOSYSTEM II

THE STROMA

ATP-SYNTHASE

ATP PRODUCING CARRIER PROTEIN

HYDROGEN IONS, $H^+$

NADP$^+$ + $H^+$

NADPH

LIGHT

PATH OF ELECTRONS

2 $H_2O$ → $O_2$ + 4 $H^+$

$H^+$

$H^+$

$H^+$
Constructing the Pieces of a Solar H₂ Fuel Generator
Nearly 100% vertically aligned, 75 µm length microwire arrays over areas > 1 cm².
Polymer Embedding of Si Rod Arrays

Cast or grow polymer
Silicon rod array on silicon substrate

Remove from substrate
Silicon rod array in polymer film

PDMS (polydimethylsiloxane)
Polymer Embedding and Wafer Reuse

Spurgeon, Boettcher et al., *Energy. Env. Sci.*
ACID-STABLE EMBEDDED MICROWIRE ARRAY

ALKALINE-STABLE EMBEDDED MICROWIRE ARRAY
Dual Wire Array Membrane

Josh Spurgeon, Lewis group, Caltech
Development of world-class tools for high-throughput characterization and analysis
Intrinsically Safe 10% STH with TiO₂-Stabilized III-V Tandem and Ni-Mo/NiOₓ Electrocatalysts
BLUEPRINT FOR AN INTEGRATED SOLAR-FUEL GENERATOR

**Radial collection of photogenerated carriers**

**Fuel and oxygen catalysts**

**Tandem light absorbers**

**Ion-conducting, gas-separation membrane**

ACCOMPLISHMENTS AND FUTURE DIRECTION
Acknowledgments
Need for Additional Primary Energy is Apparent

Case for Significant (Daunting?) Carbon-Free Energy Seems Plausible (Imperative?):
CO₂ emissions growth: 1990-1999: 1.1%/yr; 2000-2006: 3.1%/yr

Scientific/Technological Challenges

- Energy efficiency: energy security and environmental security
- Coal+gas/sequestration; nuclear/breeders; Cheap Solar Fuel
  Inexpensive conversion systems, effective storage systems

Policy Challenges

- Is Failure an Option?
- Will there be the needed commitment? In the remaining time?