Act 1.
The possibility
This may be a pivotal moment in our nation’s history
The outcome of today’s election may determine Canada's actions to combat climate change bit.ly/1RRZbmv #climateaction

How Canada’s election will decide the fate of the world. atfp.co/1PkRGWW
This may be a pivotal moment in our nation’s history

This is a pivotal moment in the world’s history
Danielle Fong, Cofounder and Chief Scientist, LightSail Energy
“The Time Machine”
If you could travel through time…

into the past…

carrying only your knowledge with you,

How far could you bring civilization forward?

How much could you change history?
Agriculture is the enabling technology of civilization

Agriculture was the efficient power of its day

Credit: Ramez Naam, “Infinite Resource”
Hunting and Gathering

Solar energy, processed through plants and animals
Limited by biology and ecology
Diffuse

Agriculture

Solar energy, More directly harnessed
Limited by technology
Distributed
Agriculture

Brought us from diffuse bands of hundreds and populations of few millions

To connected, urban, technological communities of billions

We overcame our constraints
It unlocked the potential of humanity
Fossil Fuels

Solar energy, processed through plants and animals …and geologic processes

Limited resources

You have to go find it

Diffuse and poorly distributed

Renewables

Solar energy, More directly harnessed

Limited only by technology

Distributed everywhere

You need storage
We may be at a similar time in history
The price of solar power has fallen meteorically.

The Price of Solar versus Fossil Fuels
Only 0.5% of our land would be required to power all our energy needs less than 2% of our agricultural land use

We could transcend our past energetic limitations And power amazing futures
Act 2.
The challenges
the powerplants being built now will define the biosphere for the next 5000 years
How Many Gigatons of Carbon Dioxide...?

have we released to date*?

1565 GtCO₂
fossil fuel burning and land use change
added 1850–2000

more can we “safely” release**?

405 added since 2000

860 our ‘carbon budget’

Source: Carbon Tracker Project; http://www.informationisbeautiful.net/visualizations/how-many-gigatons-of-co2/
How Many Gigatons of Carbon Dioxide...?

- **1565 GtCO₂**
  - fossil fuel burning and land use change added 1850-2000

- **405**
  - added since 2000

- **860**
  - our 'carbon budget'

- **760**
  - in fossil fuel reserves of energy companies

- **780**
  - remaining company reserves that could be developed

- **1,320**
  - other reserves including state-owned

Source: Carbon Tracker Project; [http://www.informationisbeautiful.net/visualizations/how-many-gigatons-of-co2/](http://www.informationisbeautiful.net/visualizations/how-many-gigatons-of-co2/)
Power Plants Last 60+ Years

Age of US power plants

GW

Source: EIA
Chinese Coal Demand is Growing Tremendously

If the Chinese Coal Plants Built since 2000 by 2030 last for 50 more years, we burn through $\approx \frac{3}{4}$ of our carbon budget. We do not lack for coal. Even we are unwilling to shut coal plants down.

$\approx 2$ Gigatonne increase in Chinese Coal Demand 2005-2030

1 Gigatonne Coal $\approx 2.1$ Gigatonne CO2
as the world lights up, where will the power come from?
...Just in time...

We are rapidly approaching climatic limitations

How Many Gigatons of Carbon Dioxide...?

39 gigatons

16 YEARS
average yearly emissions increase: 2.2%

Source: Carbon Tracker Project; http://www.informationisbeautiful.net/visualizations/how-many-gigatons-of-co2/
# Climate Effects

<table>
<thead>
<tr>
<th>Global Warming If Released</th>
<th>Scenario</th>
<th>Sea Level Rise by 2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>+0.8°C (1.4°F)</td>
<td>happened</td>
<td>0.85 M</td>
</tr>
<tr>
<td>+1.5°C (2.7°F)</td>
<td>inevitable</td>
<td>1.04 M</td>
</tr>
<tr>
<td>+2°C (3.6°F)</td>
<td>&quot;safe&quot; limit</td>
<td>1.24 M</td>
</tr>
<tr>
<td>+3-4°C (5.4-7.2°F)</td>
<td>tipping point</td>
<td>1.43 M</td>
</tr>
<tr>
<td>+5-6°C (9-10.8°F)</td>
<td>nightmare</td>
<td></td>
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Source: Carbon Tracker Project; [http://www.informationisbeautiful.net/visualizations/how-many-gigatons-of-co2/](http://www.informationisbeautiful.net/visualizations/how-many-gigatons-of-co2/)
<table>
<thead>
<tr>
<th>Scenario</th>
<th>Global Warming If Released</th>
<th>Sea Level Rise By 2100</th>
<th>Drowning Cities</th>
</tr>
</thead>
<tbody>
<tr>
<td>+0.8°C</td>
<td>1.4°F</td>
<td>0.85m</td>
<td>Amsterdam</td>
</tr>
<tr>
<td>+1.5°C</td>
<td>2.7°F</td>
<td>1.04m</td>
<td>New York</td>
</tr>
<tr>
<td>+2°C</td>
<td>3.6°F</td>
<td>1.24m</td>
<td>Bangkok</td>
</tr>
<tr>
<td>+3-4°C</td>
<td>5.4-7.2°F</td>
<td></td>
<td></td>
</tr>
<tr>
<td>+5-6°C</td>
<td>9-10.8°F</td>
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<tbody>
<tr>
<td>SCENARIO</td>
<td>1.4°F</td>
<td>2.7°F</td>
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<td>nightmare</td>
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**HEAT**

- More severe heat waves
- Every Euro summer a heatwave
- Italy, Spain, Greece deserts
- Unknown

Source: Carbon Tracker Project; [http://www.informationisbeautiful.net/visualizations/how-many-gigatons-of-co2/](http://www.informationisbeautiful.net/visualizations/how-many-gigatons-of-co2/)
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<th>+3-4°C (5.4-7.2°F)</th>
<th>+5-6°C (9-10.8°F)</th>
<th>over pre-industrial average temperature</th>
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<tr>
<td>SCENARIO</td>
<td>happened</td>
<td>inevitable</td>
<td>“safe” limit</td>
<td>tipping point</td>
<td>nightmare</td>
<td></td>
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| OCEAN ACIDIFICATION | 30% more acidic | stops growing | bleached | dead | 150% more acidic | oceans become more acidic as they absorb CO2 |

Source: Carbon Tracker Project; [http://www.informationisbeautiful.net/visualizations/how-many-gigatons-of-co2/](http://www.informationisbeautiful.net/visualizations/how-many-gigatons-of-co2/)
<table>
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<tr>
<th>Scenario</th>
<th>Global Warming If Released</th>
<th>Corn &amp; Wheat Yields</th>
</tr>
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<tbody>
<tr>
<td>happened</td>
<td>+0.8°C (1.4°F)</td>
<td>-10%</td>
</tr>
<tr>
<td>inevitable</td>
<td>+1.5°C (2.7°F)</td>
<td>-20%</td>
</tr>
<tr>
<td>&quot;safe&quot; limit</td>
<td>+2°C (3.6°F)</td>
<td>-30-40%</td>
</tr>
<tr>
<td>tipping point</td>
<td>+3-4°C (5.4-7.2°F)</td>
<td>unknown</td>
</tr>
<tr>
<td>nightmare</td>
<td>+5-6°C (9-10.8°F)</td>
<td>US and African corn, Indian wheat</td>
</tr>
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Source: Carbon Tracker Project; [http://www.informationisbeautiful.net/visualizations/how-many-gigatons-of-co2/](http://www.informationisbeautiful.net/visualizations/how-many-gigatons-of-co2/)
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<th>SCENARIO</th>
<th>INCREASE IN HURRICANE DESTRUCTIVE POWER</th>
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<tr>
<td>+0.8°C (1.4°F)</td>
<td>happened</td>
<td>+7.5%</td>
</tr>
<tr>
<td>+1.5°C (2.7°F)</td>
<td>inevitable</td>
<td>+15%</td>
</tr>
<tr>
<td>+2°C (3.6°F)</td>
<td>“safe” limit</td>
<td>+22.5%-30%</td>
</tr>
<tr>
<td>+3-4°C (5.4-7.2°F)</td>
<td>tipping point</td>
<td>+37.5%-45%</td>
</tr>
<tr>
<td>+5-6°C (9-10.8°F)</td>
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Source: Carbon Tracker Project; [http://www.informationisbeautiful.net/visualizations/how-many-gigatons-of-co2/](http://www.informationisbeautiful.net/visualizations/how-many-gigatons-of-co2/)
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Source: Carbon Tracker Project; http://www.informationisbeautiful.net/visualizations/how-many-gigatons-of-co2/
1870-2009 Northern hemisphere sea ice extent in million square kilometers. Blue shading indicates the pre-satellite era; data then is less reliable. In particular, the near-constant level extent in Autumn up to 1940 reflects lack of data rather than a real lack of variation.
Ice-albedo feedback (or snow-albedo feedback) is a positive feedback climate process where a change in the area of snow-covered land, ice caps, glaciers or sea ice alters the albedo. This change in albedo acts to reinforce the initial alteration in ice area.
A hidden danger lurking underground and undersea. No, it’s not Godzilla. It’s methane clathrate.
To which, I must add...
Crimes versus temperature

Data from Chicago

Tempers flare as temperatures increase

Until it's too hot to do anything
Classroom CO2 Levels

1600 ppm
Stupidity Begins

1000 ppm
Decline

400 ppm
Outside
But perhaps more important, we are quickly encountering supply limits.

The world needs so much more energy.
And we have been running out of fossil fuels.
• Oil production has faltered, even as capex has soared
• Capex productivity has fallen by a factor of five since 2000
• Observed decline trend now approaching 5% per year
We have never before spent so much searching and found so little!

We spent a record $700 billion search for oil last year!

Replacing only 4.5 months of production in 12 months!

Oil is half the world's commodity trade and half the cost structure of the other half!
“Anyone who believes exponential growth can go on forever in a finite world is either a madman or an economist” - Kenneth Boulding
“Anyone who believes exponential growth can go on forever in a finite world is either a madman or an economist” - Kenneth Boulding

“…or a technologist, who sees how technology can transcend our past limitations” - Danielle Fong
Act 3.
Getting to work
Won’t all this efficiency be awfully expensive?
There is no free lunch

This lunch will buy you dinner
Thomas Edison’s First Powerplant

Pearl Street Station

In a sense more efficient Than most modern power plants

Don’t just waste the heat, harness it
Natural gas: Local leaks impact global climate
EDF and Google Earth Outreach use new approach to pinpoint climate pollution

Natural gas heats our homes and cooks our dinner. But when natural gas—mostly methane—leaks into the air, it’s a big problem for the climate. So EDF and Google Earth Outreach teamed up to build a faster, cheaper way to find and assess leaks under our streets and sidewalks. We tested it as part of a pilot mapping program, and here’s what we found.

Boston: Older pipes, more leaks

Indianapolis: Newer pipes, fewer leaks
Alberta’s Oil Sands Raise Flaring Emissions as Rules Lag

The World Bank estimates that over 150 billion cubic metres of natural gas are flared or vented annually. This amount of gas is worth approximately 30.6 billion dollars and is equivalent to 25 percent of the United States's yearly gas consumption or 30 percent of the European Union's annual gas consumption.[10]
**Snapshot of waste.** Infrared cameras quickly show where heat is escaping from a building. The older building on the right, for instance, has leaky windows.
If you could travel through time…
from the future into the present…
carrying only your knowledge with you,

You would already know what could work

What would you build?
How far could you bring civilization forward?
And what would you need to know?
We can provide energy storage, heating, hot water, and air conditioning for profound increases in efficiency.
My own story...
2000: age 12

physics at Dalhousie University
2005: begin PhD at Princeton University
Studying energy with nuclear fusion
2007: Decide it is not fast enough, move to Silicon Valley to become and entrepreneur and chase my destiny
Problem:
Renewable Energy is Intermittent
We Need to Store the Energy
A Hot Day in Texas

Electricity prices skyrocket on a hot day in Texas. What if wind or solar power could be stored cheaply and delivered when it’s needed? More profit for the wind and solar farms, low cost energy for the users, greener energy for the world.
A solar powered world is inevitable — *if* energy storage can be made economical at scale.
All the batteries on Earth can store only 10 minutes of the world's electricity needs.
We need technology that is

- Low Capital Cost
- Long Service Life
- Available at Global Scale
- Efficient Enough
We have discovered how to do this with compressed air

**Low Capital Cost**
- < 1/3rd the cost of batteries
- Target cost < $100 / kWh

**Long Service Life**
- 20-30 year lifetime
- 20000+ cycles
- Tanks already certified

**Available at Global Scale**
- Harnessing engine manufacturing
- Only need ~1% of manufacturing capacity

**Efficient Enough**
- From 25% efficiency historically
  to
- 60 - 70% efficiency
  90+% w/ waste heat
LightSail’s breakthrough solution: Regenerative air energy storage (RAES)

The RAES air compressor / expander: a major thermodynamic innovation

LightSail’s proprietary air storage technology can be sited anywhere

Major advances in both compressor design and air storage technology
Even if you know what to build, it was a long road

How the world criticizes ideas...
why don’t people already use compressed air? thermodynamics fights you

\[ PV = NRT \]

compress air and it gets hot, and fights the compression
when compressing, you want the air to be as *cool* as possible
when expanding, you want the air to be as *warm* as possible
nobody had yet made this practical
to fight the heat of compression
we use water spray
During air compression, mechanical energy is converted into heat. Spray water directly into the air during compression.
Our Approach

During air compression, mechanical energy is converted into heat. Spray water directly into the air during compression.

Store the compressed air in a tank.

Exchange heat between the water and heat storage.

During air expansion, spray warm water into the expanding air. Heat energy in the water is absorbed by the air and is converted into mechanical energy.
Our Approach

During air compression, mechanical energy is converted into heat. Spray water directly into the air during compression. Store the compressed air in a tank.

Exchange heat between the water and heat storage.

During air expansion, spray warm water into the expanding air. Heat energy in the water is absorbed by the air and is converted into mechanical energy.
During air compression, mechanical energy is converted into heat. Spray water directly into the air during compression.

- Store the compressed air in a tank.
- Exchange heat between the water and heat storage.

During air expansion, spray warm water into the expanding air. Heat energy in the water is absorbed by the air and is converted into mechanical energy.
why don’t people already use compressed air? thermodynamics fights you

\[ PV = NRT \]

compress air and it gets hot, and fights the compression

![Efficiency (One Way) graph]

- Friction
- Electrical Loss
- Thermodynamic Loss
- Recoverable Energy

77% improvement in efficiency
Danielle Fong  
Cofounder, CSO

Began PhD at 17  
Princeton Plasma Physics Lab

Dr. Steve Crane  
Cofounder, CEO

Physics at MIT,  
Caltech, and the  
Scripps Institute

Ed Berlin  
Cofounder, CTO

MIT electrical engineer;  
Engineer of the Year;  
Grumman Aerospace

Kevin Walter  
VP Mechanical Dev

Protege of Roger Penske  
Developed engines which  
won racing championships

2009: Combined with world class cofounders
2010: industrial scale proof of concept
2011: complete scientific demonstration
2012: secure backing
Lesson: secure backers allows you to beat the odds
2012: design of product
2013: build product prototype
2014: we demonstrated the technological breakthrough
we built it
The compression process, at full pressure
How water spray effects efficiency

Before “Adiabatic”

Absolute Thermodynamic Ideal

Compression
HP Valve Opening

Max Volume

Time (ms)

Water Flow (kg/s)

Min Volume
How water spray effects efficiency

Before "Adiabatic"

Absolute Thermodynamic Ideal
Levelized Cost of Energy ($/kWh)

- Previous Batteries: $0.242
- Tesla Lithium Ion Power Pack: $0.08 + $0.128 + $0.010 + $0.03 + $0.04 = $0.258
- Peak Retail Electricity: $0.28
- LightSail Gen 1: $0.08 + $0.011 + $0.086 + $0.005 + $0.043 = $0.22
- LightSail Gen 2: $0.08 + $0.011 + $0.086 + $0.005 + $0.043 = $0.22

Efficiency Penalty
Charging Cost @ 100% RTE
O&M
Depth of Discharge Penalty
Degradation Penalty
Capital Cost
Listed Oil Majors: Capex and Crude Oil Production

- Oil production has faltered, even as capex has soared
- Capex productivity has fallen by a factor of five since 2000
- Observed decline trend now approaching 5% per year
Us
LightSail Energy

Yes, we are raising a funding round. dfong@lightsailenergy.com