



1  
00:00:01,000 --> 00:00:04,000  
[music playing]

2  
00:00:16,800 --> 00:00:22,600  
- Welcome to the 2016  
NASA Ames Summer Series.

3  
00:00:22,600 --> 00:00:25,400  
To achieve  
human space exploration

4  
00:00:25,400 --> 00:00:27,966  
envisioned  
by science-fiction authors,

5  
00:00:27,966 --> 00:00:33,966  
we must take into consideration  
life support requirements.

6  
00:00:33,966 --> 00:00:37,366  
When searching  
for habitable planets,

7  
00:00:37,366 --> 00:00:40,666  
we look for liquid water.

8  
00:00:40,666 --> 00:00:44,900  
Water is key to life  
as we know it,

9  
00:00:44,900 --> 00:00:49,133  
and for human space exploration.

10  
00:00:49,133 --> 00:00:50,833  
Today's presentation,

11  
00:00:50,833 --> 00:00:54,333  
entitled  
"Synthetic Biological Membrane,"

12

00:00:54,333 --> 00:01:00,133  
will be given  
by Mr. Michael Flynn.

13

00:01:00,133 --> 00:01:02,666  
He is the Principal Investigator  
and lead

14

00:01:02,666 --> 00:01:05,233  
for the Water Technology  
Development Laboratory

15

00:01:05,233 --> 00:01:07,933  
here at NASA Ames  
Research Center

16

00:01:07,933 --> 00:01:13,600  
and has over 26, 27 years  
of experience.

17

00:01:16,733 --> 00:01:18,466  
He earned  
a Bachelor's of Science

18

00:01:18,466 --> 00:01:20,166  
at San Francisco State  
University

19

00:01:20,166 --> 00:01:22,400  
in Mechanical Engineering.

20

00:01:22,400 --> 00:01:24,866  
He has received numerous awards.

21

00:01:24,866 --> 00:01:26,866  
A few of are

22

00:01:26,866 --> 00:01:31,966

two R&D 100 Awards,  
a Wright Brothers Medal,

23

00:01:31,966 --> 00:01:35,000  
an Arch T. Caldwell Merit Award,

24

00:01:35,000 --> 00:01:38,200  
and six NASA Spotlight awards.

25

00:01:38,200 --> 00:01:40,833  
Please join me  
in welcoming Michael Flynn.

26

00:01:40,833 --> 00:01:43,833  
[applause]

27

00:01:46,566 --> 00:01:48,833  
- Well, thank you  
for coming today.

28

00:01:48,833 --> 00:01:50,666  
I'm gonna give a presentation  
today that deals

29

00:01:50,666 --> 00:01:52,633  
with an area of research  
called life support.

30

00:01:52,633 --> 00:01:54,433  
And it's really  
gonna primarily focus

31

00:01:54,433 --> 00:01:57,166  
on sort of advanced  
research areas in life support

32

00:01:57,166 --> 00:01:58,633  
and sort of a new direction

33

00:01:58,633 --> 00:02:02,800  
for enabling  
human exploration of space.

34  
00:02:02,800 --> 00:02:04,533  
So the objective of this,  
primarily,

35  
00:02:04,533 --> 00:02:06,066  
is to kind of put ideas  
into your heads,

36  
00:02:06,066 --> 00:02:07,200  
ideas that you,

37  
00:02:07,200 --> 00:02:09,300  
as individual researchers  
here at NASA,

38  
00:02:09,300 --> 00:02:11,000  
might later on write proposals

39  
00:02:11,000 --> 00:02:12,700  
and do research and funding

40  
00:02:12,700 --> 00:02:17,566  
to enable those future missions  
to occur.

41  
00:02:17,566 --> 00:02:20,333  
So the first question is,  
what is life support?

42  
00:02:20,333 --> 00:02:22,766  
All right, so life support  
basically is a field of research

43  
00:02:22,766 --> 00:02:24,733  
that addresses all aspects

44

00:02:24,733 --> 00:02:27,233

of keeping human beings  
alive in space.

45

00:02:27,233 --> 00:02:30,233

The easy part of space flight  
is getting to space.

46

00:02:30,233 --> 00:02:31,766

You get a big aluminum can,

47

00:02:31,766 --> 00:02:33,833

you buy as much explosives  
as you can,

48

00:02:33,833 --> 00:02:35,600

you get a match,  
you light the match,

49

00:02:35,600 --> 00:02:37,633

and, boom,  
you're in outer space.

50

00:02:37,633 --> 00:02:39,366

But now you got  
to do something there.

51

00:02:39,366 --> 00:02:41,400

And if it's  
a human-tended mission,

52

00:02:41,400 --> 00:02:43,100

that can be very complicated,

53

00:02:43,100 --> 00:02:45,100

because you need  
to keep the human being alive.

54

00:02:45,100 --> 00:02:47,633

All those systems that we  
take for granted on the earth--

55

00:02:47,633 --> 00:02:50,466  
the ecosystems, the biospheres  
that support us on earth--

56

00:02:50,466 --> 00:02:52,500  
don't exist  
in that aluminum can.

57

00:02:52,500 --> 00:02:54,233  
So those functions  
need to be turned

58

00:02:54,233 --> 00:02:57,000  
into devices, into machines,  
into small boxes,

59

00:02:57,000 --> 00:02:58,566  
loaded into the spacecraft,

60

00:02:58,566 --> 00:03:01,633  
and then operate  
to keep you alive in space.

61

00:03:01,633 --> 00:03:03,866  
So the main objective  
of life support programs

62

00:03:03,866 --> 00:03:05,600  
is to keep the astronaut alive.

63

00:03:05,600 --> 00:03:07,233  
It's always  
extremely embarrassing

64

00:03:07,233 --> 00:03:08,500  
when the astronaut gets killed,

65

00:03:08,500 --> 00:03:10,300

so we don't want  
to have any of that happening.

66

00:03:10,300 --> 00:03:11,633

We want to provide  
an environment

67

00:03:11,633 --> 00:03:14,933

that is entirely safe  
for space flight applications.

68

00:03:14,933 --> 00:03:16,966

And that sounds  
like a trivial task,

69

00:03:16,966 --> 00:03:19,433

but that actually  
is the most important task

70

00:03:19,433 --> 00:03:22,033

of the life support system, is,  
it has to be robust,

71

00:03:22,033 --> 00:03:23,566

and it cannot fail

72

00:03:23,566 --> 00:03:27,600

in a manner that allows  
a human life to be taken

73

00:03:27,600 --> 00:03:29,000

as part of the mission.

74

00:03:29,000 --> 00:03:31,300

The other part of it is to  
provide a habitable environment.

75

00:03:31,300 --> 00:03:33,333

Space flight  
is extremely expensive.

76

00:03:33,333 --> 00:03:35,066  
To keep an astronaut in space

77

00:03:35,066 --> 00:03:37,133  
costs a huge amount  
of money per hour.

78

00:03:37,133 --> 00:03:38,800  
And so providing an environment

79

00:03:38,800 --> 00:03:42,300  
where they can be  
very, very productive is key.

80

00:03:42,300 --> 00:03:46,066  
Astronauts work, on average,  
12, 16 hours a day.

81

00:03:46,066 --> 00:03:47,833  
We try to get maximum work  
out of them

82

00:03:47,833 --> 00:03:49,100  
because of the expense

83

00:03:49,100 --> 00:03:50,666  
associated with  
having them in space.

84

00:03:50,666 --> 00:03:53,566  
So it's not enough to have,  
like, a camping environment.

85

00:03:53,566 --> 00:03:56,166  
It has to be  
a high-quality environment.

86

00:03:56,166 --> 00:03:58,666

The life support system  
has to operate flawlessly

87

00:03:58,666 --> 00:04:00,900

behind the scenes.

88

00:04:00,900 --> 00:04:02,066

We want to minimize the amount

89

00:04:02,066 --> 00:04:03,700

of maintenance  
associated with it.

90

00:04:03,700 --> 00:04:05,633

And then, the final  
and the most important part

91

00:04:05,633 --> 00:04:07,033

deals with cost.

92

00:04:07,033 --> 00:04:10,400

We have the ability to send  
humans to Mars right now.

93

00:04:10,400 --> 00:04:12,700

We have the ability  
to colonize Mars right now.

94

00:04:12,700 --> 00:04:14,266

The technology does exist.

95

00:04:14,266 --> 00:04:17,000

The problem is,  
the price is too high.

96

00:04:17,000 --> 00:04:18,800

NASA has done several missions

97

00:04:18,800 --> 00:04:21,666

where we've costed out the entire process of going to Mars,

98

00:04:21,666 --> 00:04:24,200

and they average around \$400 billion.

99

00:04:24,200 --> 00:04:26,500

And Congress has told us that that is too much.

100

00:04:26,500 --> 00:04:29,266

We are not gonna give you \$400 billion to do this mission.

101

00:04:29,266 --> 00:04:31,300

You need to be under \$100 billion,

102

00:04:31,300 --> 00:04:33,900

and preferably around a half a billion dollars.

103

00:04:33,900 --> 00:04:35,700

So one of the objectives of life support

104

00:04:35,700 --> 00:04:38,266

is to reduce the cost of keeping human beings alive.

105

00:04:38,266 --> 00:04:39,400

If you can imagine,

106

00:04:39,400 --> 00:04:41,333

if you have to bring water and air with you,

107

00:04:41,333 --> 00:04:43,733

that's an extremely  
expensive proposition.

108

00:04:43,733 --> 00:04:46,400

So the ability  
to recycle things in situ

109

00:04:46,400 --> 00:04:47,866

has a dramatic impact

110

00:04:47,866 --> 00:04:52,433

on the cost  
of conducting these missions.

111

00:04:52,433 --> 00:04:54,366

I'm sorry, I went the wrong way.

112

00:04:54,366 --> 00:04:56,466

So we know a lot  
about life support.

113

00:04:56,466 --> 00:04:58,300

We know a lot about  
keeping human beings alive.

114

00:04:58,300 --> 00:04:59,866

And the reason we know  
so much about it

115

00:04:59,866 --> 00:05:01,200

is because we've been doing it.

116

00:05:01,200 --> 00:05:04,800

We've been doing it  
since at least 2009,

117

00:05:04,800 --> 00:05:07,333

and we've been doing it on  
the International Space Station.

118

00:05:07,333 --> 00:05:10,533

The International Space Station  
is probably the most sustainable

119

00:05:10,533 --> 00:05:12,700

habitat ever developed  
by mankind,

120

00:05:12,700 --> 00:05:15,433

if you subtract out  
all the environment catastrophe

121

00:05:15,433 --> 00:05:17,066

associated with launching it.

122

00:05:17,066 --> 00:05:18,733

On the International  
Space Station,

123

00:05:18,733 --> 00:05:19,900

we recycle all the water.

124

00:05:19,900 --> 00:05:21,366

So if you want to be  
an astronaut,

125

00:05:21,366 --> 00:05:23,266

you better be prepared  
to drink your own urine,

126

00:05:23,266 --> 00:05:24,600

because that's the only water

127

00:05:24,600 --> 00:05:26,533

that's available on  
the International Space Station.

128

00:05:26,533 --> 00:05:27,866

In fact, you better be prepared

129

00:05:27,866 --> 00:05:30,100  
to drink the person  
sitting next to you's urine,

130

00:05:30,100 --> 00:05:31,533  
because that's the only water.

131

00:05:31,533 --> 00:05:33,866  
We also recycle  
the humidity condensate,

132

00:05:33,866 --> 00:05:36,100  
the breath, the water  
in your breath that comes out.

133

00:05:36,100 --> 00:05:37,133  
You know, here on earth,

134

00:05:37,133 --> 00:05:38,800  
we talk about  
carbon sequestration

135

00:05:38,800 --> 00:05:39,800  
and global warming.

136

00:05:39,800 --> 00:05:41,533  
Well, we do full  
carbon sequestration

137

00:05:41,533 --> 00:05:42,833  
on the International  
Space Station.

138

00:05:42,833 --> 00:05:45,466  
We remove all the carbon dioxide  
out of the atmosphere.

139

00:05:45,466 --> 00:05:47,600  
We control around 400 PPM.

140  
00:05:47,600 --> 00:05:50,300  
That carbon is turned  
into methane, a fuel.

141  
00:05:50,300 --> 00:05:52,966  
We also have research looking  
at turning to graphitic carbon,

142  
00:05:52,966 --> 00:05:55,666  
and we're starting work looking  
at turning it to bioplastics

143  
00:05:55,666 --> 00:05:57,833  
so we can make things like  
spare parts and things like that

144  
00:05:57,833 --> 00:06:00,333  
from the carbon dioxide  
in the atmosphere.

145  
00:06:00,333 --> 00:06:03,600  
The oxygen you breathe,  
that's come by--you guessed it.

146  
00:06:03,600 --> 00:06:05,333  
That's also coming  
from your urine as well.

147  
00:06:05,333 --> 00:06:08,033  
So we want to keep  
that urine theme going.

148  
00:06:08,033 --> 00:06:11,166  
We purify the urine,  
we turn it into water,

149  
00:06:11,166 --> 00:06:13,433

and then we put it into  
an oxygen generation system

150

00:06:13,433 --> 00:06:16,266

where we split the oxygen  
into hydrogen and oxygen,

151

00:06:16,266 --> 00:06:18,500

and the oxygen  
is what you breathe, right?

152

00:06:18,500 --> 00:06:20,766

So the International  
Space Station is like,

153

00:06:20,766 --> 00:06:23,200

if you took a bunch of engineers  
and you locked them in a room

154

00:06:23,200 --> 00:06:25,266

and told them, we want  
the most sustainable system

155

00:06:25,266 --> 00:06:26,533

you can possibly develop,

156

00:06:26,533 --> 00:06:28,000

and money is no object.

157

00:06:28,000 --> 00:06:30,333

You can spend as much money  
on it as you possibly want,

158

00:06:30,333 --> 00:06:32,666

you'd end up with something like  
the International Space Station,

159

00:06:32,666 --> 00:06:34,666

completely solar-powered.

160  
00:06:34,666 --> 00:06:36,500  
It's been operating  
since about 2009,

161  
00:06:36,500 --> 00:06:39,866  
so we have the benefit of  
having learned all the lessons

162  
00:06:39,866 --> 00:06:42,800  
associated with building  
and operating these systems.

163  
00:06:42,800 --> 00:06:45,933  
And those lessons learned  
are key to providing direction

164  
00:06:45,933 --> 00:06:47,800  
for future research  
and development

165  
00:06:47,800 --> 00:06:48,866  
of life support systems,

166  
00:06:48,866 --> 00:06:50,466  
for instance,  
for the colonization,

167  
00:06:50,466 --> 00:06:52,100  
exploration of Mars,

168  
00:06:52,100 --> 00:06:57,000  
going to asteroids,  
or going to other planets.

169  
00:06:57,000 --> 00:06:59,266  
So, life support, pretty simple.

170  
00:06:59,266 --> 00:07:01,533  
You produce outputs--

171

00:07:01,533 --> 00:07:04,566

waste water, urine,  
humidity condensate,

172

00:07:04,566 --> 00:07:05,866

feces water.

173

00:07:05,866 --> 00:07:07,266

You produce carbon dioxide.

174

00:07:07,266 --> 00:07:08,966

You produce volatile organics.

175

00:07:08,966 --> 00:07:09,966

You all smell.

176

00:07:09,966 --> 00:07:11,400

You produce volatile organics,

177

00:07:11,400 --> 00:07:14,533

solid waste in garbage  
and feces, and heat.

178

00:07:14,533 --> 00:07:16,066

And the objective  
of the life support

179

00:07:16,066 --> 00:07:17,800

is to take all of those outputs

180

00:07:17,800 --> 00:07:20,333

and make them  
into the inputs, right?

181

00:07:20,333 --> 00:07:24,133

So you can think of it  
as a spacesuit,

182

00:07:24,133 --> 00:07:26,333

a space station, on the earth.

183

00:07:26,333 --> 00:07:28,700

But the idea is that you have  
to close all the loops,

184

00:07:28,700 --> 00:07:30,500

and you have to balance  
the entire system

185

00:07:30,500 --> 00:07:31,933

from the standpoint of mass.

186

00:07:31,933 --> 00:07:34,033

So the only thing  
you have to put in is energy

187

00:07:34,033 --> 00:07:36,933

in order to keep something  
alive indefinitely.

188

00:07:36,933 --> 00:07:39,200

And when you look at that,  
the biggest potential--

189

00:07:39,200 --> 00:07:41,233

So this is a pie chart  
that shows,

190

00:07:41,233 --> 00:07:43,133

if you didn't do  
any recycling at all,

191

00:07:43,133 --> 00:07:45,833

you just brought everything  
with you on a mission to Mars,

192

00:07:45,833 --> 00:07:47,300

what would be the relative mass?

193

00:07:47,300 --> 00:07:50,666

And as you can see, water is  
the huge, huge piece of the pie.

194

00:07:50,666 --> 00:07:54,333

Everything else is  
a much smaller piece of the pie.

195

00:07:54,333 --> 00:07:56,233

Most of the missions  
that we've done in the past,

196

00:07:56,233 --> 00:07:58,800

the one I was referring to  
that was \$400 billion,

197

00:07:58,800 --> 00:08:00,533

assumed an open-loop case,

198

00:08:00,533 --> 00:08:02,900

assumed that you brought  
all of your waste--

199

00:08:02,900 --> 00:08:04,266

brought all your water with you

200

00:08:04,266 --> 00:08:05,866

and then turned everything  
into waste.

201

00:08:05,866 --> 00:08:07,833

So very expensive  
from the standpoint

202

00:08:07,833 --> 00:08:10,033

of bringing these materials  
along with you.

203

00:08:10,033 --> 00:08:12,033

So this is the area  
that I primarily work in,

204

00:08:12,033 --> 00:08:13,200

which is water,

205

00:08:13,200 --> 00:08:15,200

because that's  
the big aspect of it,

206

00:08:15,200 --> 00:08:17,566

the big part of it.

207

00:08:17,566 --> 00:08:19,033

On the International  
Space Station,

208

00:08:19,033 --> 00:08:21,100

we have  
a very complicated system.

209

00:08:21,100 --> 00:08:22,666

I kind of went through it  
a little bit.

210

00:08:22,666 --> 00:08:24,200

I'll go through it again  
with this diagram.

211

00:08:24,200 --> 00:08:25,666

But basically,  
you have the crew.

212

00:08:25,666 --> 00:08:27,466

They're the center  
of the whole system.

213

00:08:27,466 --> 00:08:30,133

The crew are producing  
water and urine,

214

00:08:30,133 --> 00:08:31,900

and they're producing water  
in their breath

215

00:08:31,900 --> 00:08:33,400

that goes into  
the cabin atmosphere.

216

00:08:33,400 --> 00:08:35,033

And then they're also  
producing feces.

217

00:08:35,033 --> 00:08:36,833

Right now we don't do anything  
with the feces,

218

00:08:36,833 --> 00:08:40,233

but we are working on projects  
for recycling feces as well.

219

00:08:40,233 --> 00:08:42,900

The humidity goes through  
a condensing heat exchanger

220

00:08:42,900 --> 00:08:44,266

where the water is removed,

221

00:08:44,266 --> 00:08:46,000

and then the carbon dioxide  
is passed

222

00:08:46,000 --> 00:08:47,700

to a CO2 removal system

223

00:08:47,700 --> 00:08:49,800

where the carbon dioxide  
is removed out of it.

224

00:08:49,800 --> 00:08:52,233

The urine is sent  
to a urine recovery system,

225

00:08:52,233 --> 00:08:53,333

where it's purified,

226

00:08:53,333 --> 00:08:54,566

and then that purified water

227

00:08:54,566 --> 00:08:56,500

is combined  
with the condensate water

228

00:08:56,500 --> 00:08:58,000

into another piece of equipment

229

00:08:58,000 --> 00:08:59,600

that just makes it  
into drinking water,

230

00:08:59,600 --> 00:09:02,366

makes sure it's pure,  
makes sure it's sterile water.

231

00:09:02,366 --> 00:09:05,566

Some of that water goes back  
to our oxygen generation system,

232

00:09:05,566 --> 00:09:07,766

where the hydrogen  
and the oxygen split.

233

00:09:07,766 --> 00:09:09,900

The oxygen is provided  
back to the crew.

234

00:09:09,900 --> 00:09:13,633

The hydrogen, then, is provided to the CO2 reduction system

235

00:09:13,633 --> 00:09:17,666  
and is used to reduce the CO2 into things like methane,

236

00:09:17,666 --> 00:09:20,366  
graphitic carbon,  
or bioplastics,

237

00:09:20,366 --> 00:09:23,566  
if you want to go that far to do that.

238

00:09:23,566 --> 00:09:25,300  
So, like I said,  
we have a lot of experience.

239

00:09:25,300 --> 00:09:28,266  
We've been operating  
the ISS water recycling system

240

00:09:28,266 --> 00:09:29,600  
since 2009.

241

00:09:29,600 --> 00:09:31,033  
Here's a picture of the rack.

242

00:09:31,033 --> 00:09:32,366  
It's a double rack.

243

00:09:32,366 --> 00:09:35,366  
You're looking at about  
\$500 million worth of equipment

244

00:09:35,366 --> 00:09:36,733  
right there on that system.

245

00:09:36,733 --> 00:09:38,833

Very, very expensive  
piece of equipment.

246

00:09:38,833 --> 00:09:41,100

And the reason for that  
is that--

247

00:09:41,100 --> 00:09:43,200

well, this picture's not  
actually quite right.

248

00:09:43,200 --> 00:09:46,666

The reason for that is,  
it's in microgravity, right?

249

00:09:46,666 --> 00:09:49,266

So that means  
that no technologies

250

00:09:49,266 --> 00:09:50,366

that we use on the ground

251

00:09:50,366 --> 00:09:52,400

actually work  
for this application.

252

00:09:52,400 --> 00:09:55,166

Almost every technology  
that's utilized in this system

253

00:09:55,166 --> 00:09:57,366

was custom-designed  
for microgravity.

254

00:09:57,366 --> 00:09:59,866

So, for instance, there  
are really no commercial pumps

255

00:09:59,866 --> 00:10:01,266

that work in microgravity,

256

00:10:01,266 --> 00:10:04,100  
with the exception maybe  
of peristaltic pumps.

257

00:10:04,100 --> 00:10:06,300  
Sensors, connectivity sensors,  
things like that,

258

00:10:06,300 --> 00:10:07,933  
they don't work  
in microgravity either.

259

00:10:07,933 --> 00:10:10,666  
Almost all of the content  
of this piece of equipment

260

00:10:10,666 --> 00:10:13,500  
had to be developed  
through research programs,

261

00:10:13,500 --> 00:10:16,133  
flight-tested for  
microgravity application,

262

00:10:16,133 --> 00:10:17,866  
and then implemented.

263

00:10:17,866 --> 00:10:21,433  
And it's something you guys  
all can relate to, right?

264

00:10:21,433 --> 00:10:23,200  
I mean, if I took a toilet,

265

00:10:23,200 --> 00:10:25,133  
bolted it to the ceiling  
in this room,

266

00:10:25,133 --> 00:10:26,533

and then told you,  
that's the bathroom,

267

00:10:26,533 --> 00:10:27,700

you got to use that toilet,

268

00:10:27,700 --> 00:10:29,200

you'd realize the problems

269

00:10:29,200 --> 00:10:31,133

associated  
with microgravity function.

270

00:10:31,133 --> 00:10:32,600

Water doesn't flow downhill.

271

00:10:32,600 --> 00:10:34,266

All of the assumptions  
that we use

272

00:10:34,266 --> 00:10:36,366

in water recycling systems  
here terrestrially

273

00:10:36,366 --> 00:10:38,033

really don't apply  
when you start

274

00:10:38,033 --> 00:10:41,000

doing microgravity  
experiments with them.

275

00:10:41,000 --> 00:10:43,800

The other thing is that  
the International Space Station

276

00:10:43,800 --> 00:10:46,700

has turned into this

huge, complicated machine.

277

00:10:46,700 --> 00:10:49,500

It's definitely  
the most complicated device

278

00:10:49,500 --> 00:10:51,700

that humankind has ever made.

279

00:10:51,700 --> 00:10:54,766

And, of that system,  
the most complicated components

280

00:10:54,766 --> 00:10:56,500

are the life support system.

281

00:10:56,500 --> 00:10:58,033

Not only the most complicated,

282

00:10:58,033 --> 00:10:59,866

but also the most  
dangerous components

283

00:10:59,866 --> 00:11:01,433

are the life support system.

284

00:11:01,433 --> 00:11:03,666

For instance, I talked about  
the water electrolyzer

285

00:11:03,666 --> 00:11:05,033

that makes oxygen.

286

00:11:05,033 --> 00:11:08,033

It takes water, it splits it  
into hydrogen and oxygen.

287

00:11:08,033 --> 00:11:09,900

When you have hydrogen

and oxygen together,

288

00:11:09,900 --> 00:11:12,200

you have what's called  
a bomb, right?

289

00:11:12,200 --> 00:11:14,600

And so that system's  
extremely dangerous,

290

00:11:14,600 --> 00:11:16,966

and it's enclosed  
in a Hastelloy

291

00:11:16,966 --> 00:11:19,666

explosion-proof container

292

00:11:19,666 --> 00:11:20,966

so that, if it was to explode,

293

00:11:20,966 --> 00:11:23,533

it couldn't take out  
the entire space station.

294

00:11:23,533 --> 00:11:25,666

The urine--we don't want  
the urine to go bad.

295

00:11:25,666 --> 00:11:27,866

We don't want bacteria  
to grow into it and decompose.

296

00:11:27,866 --> 00:11:30,533

So we add a compound  
called chromic acid to it.

297

00:11:30,533 --> 00:11:33,366

Chromic acid  
is a strong carcinogen.

298

00:11:33,366 --> 00:11:34,966

It's also extremely corrosive.

299

00:11:34,966 --> 00:11:36,400

And it turns that urine

300

00:11:36,400 --> 00:11:39,366

into the most hazardous fluid on  
the International Space Station.

301

00:11:39,366 --> 00:11:41,500

There's no other fluid  
that even comes close

302

00:11:41,500 --> 00:11:42,900

to as hazardous as that.

303

00:11:42,900 --> 00:11:45,233

And then we purify it  
and let the astronauts drink it.

304

00:11:45,233 --> 00:11:48,000

So kind of a crazy way  
of doing it.

305

00:11:48,000 --> 00:11:49,866

So one of the key things  
that we've learned

306

00:11:49,866 --> 00:11:51,766

from building  
the International Space Station

307

00:11:51,766 --> 00:11:54,000

is that we have  
this real significant problem,

308

00:11:54,000 --> 00:11:57,333

which is, there's only 24 hours

in a day, right?

309

00:11:57,333 --> 00:11:59,800

So you can only do  
24 hours a day

310

00:11:59,800 --> 00:12:01,866

worth of maintenance  
on the system.

311

00:12:01,866 --> 00:12:03,966

And so if your system  
gets really complex

312

00:12:03,966 --> 00:12:06,633

and you need, for instance,  
26 hours a day

313

00:12:06,633 --> 00:12:07,900

in order to maintain it,

314

00:12:07,900 --> 00:12:10,033

you've created  
a significant problem.

315

00:12:10,033 --> 00:12:12,200

And that's where we are with  
the International Space Station,

316

00:12:12,200 --> 00:12:13,700

that the maintenance  
requirements

317

00:12:13,700 --> 00:12:16,533

associated with this  
incredibly complex system

318

00:12:16,533 --> 00:12:18,800

are becoming  
extremely problematic.

319

00:12:18,800 --> 00:12:21,266

It's becoming very difficult  
for us to keep up

320

00:12:21,266 --> 00:12:23,833

on all the maintenance  
requirements from them.

321

00:12:23,833 --> 00:12:25,400

So this is one  
of the key lessons learned

322

00:12:25,400 --> 00:12:26,466

from this system,

323

00:12:26,466 --> 00:12:29,300

which is that maintenance  
and repair

324

00:12:29,300 --> 00:12:31,133

of these mechanical devices--

325

00:12:31,133 --> 00:12:32,500

and the International  
Space Station

326

00:12:32,500 --> 00:12:34,266

is a mechanical device--

327

00:12:34,266 --> 00:12:37,366

has become a real significant  
problem for us.

328

00:12:37,366 --> 00:12:38,600

And if we're gonna go to Mars,

329

00:12:38,600 --> 00:12:40,033

if we're gonna go

on a Mars mission,

330

00:12:40,033 --> 00:12:41,700

which is like

a two- to three-year mission

331

00:12:41,700 --> 00:12:43,033

to Mars and back,

332

00:12:43,033 --> 00:12:45,333

We're not gonna be able

to do this kind of maintenance.

333

00:12:45,333 --> 00:12:47,800

On ISS, we can bring

equipment down to earth.

334

00:12:47,800 --> 00:12:48,900

It's in low earth orbit.

335

00:12:48,900 --> 00:12:50,033

We can bring equipment down,

336

00:12:50,033 --> 00:12:51,900

we can repair it,

and we can return it.

337

00:12:51,900 --> 00:12:54,800

On a Mars mission,

we can't do any of that.

338

00:12:54,800 --> 00:12:57,600

Any spare parts have to go

along with the mission

339

00:12:57,600 --> 00:12:58,866

as primary payload,

340

00:12:58,866 --> 00:13:01,733

and they really drive  
the price up dramatically.

341

00:13:01,733 --> 00:13:03,800

For these types of systems,  
for mechanical systems,

342

00:13:03,800 --> 00:13:07,166

NASA typically requires  
double or triple redundancy.

343

00:13:07,166 --> 00:13:08,366

And that means you either need

344

00:13:08,366 --> 00:13:10,200

to have three pieces  
of equipment,

345

00:13:10,200 --> 00:13:11,766

or you need to have spare parts

346

00:13:11,766 --> 00:13:15,433

in order to replace the key  
failing components three times.

347

00:13:15,433 --> 00:13:17,466

Remember I talked about  
the price of these missions

348

00:13:17,466 --> 00:13:19,400

at around \$400 billion,

349

00:13:19,400 --> 00:13:22,633

that we need to drive the price  
down to below \$1 billion?

350

00:13:22,633 --> 00:13:24,233

Well, an easy low-hanging fruit

351

00:13:24,233 --> 00:13:27,033  
would be to develop systems  
that are so reliable,

352

00:13:27,033 --> 00:13:29,666  
that they don't need those kind  
of redundant systems, right?

353

00:13:29,666 --> 00:13:32,333  
We could remove \$2 billion  
to \$3 billion

354

00:13:32,333 --> 00:13:33,400  
out of that price tag

355

00:13:33,400 --> 00:13:35,666  
by taking that kind  
of an approach.

356

00:13:35,666 --> 00:13:37,100  
Now, we're not the only ones.

357

00:13:37,100 --> 00:13:39,566  
The ISS program is not the only  
ones that have observed this.

358

00:13:39,566 --> 00:13:41,466  
The National Research Council

359

00:13:41,466 --> 00:13:43,866  
has also published a report  
on this topic,

360

00:13:43,866 --> 00:13:45,066  
looking at the lessons learned

361

00:13:45,066 --> 00:13:46,633  
from the International  
Space Station,

362

00:13:46,633 --> 00:13:48,733

and basically came  
to the same conclusion,

363

00:13:48,733 --> 00:13:50,866

that unless we make  
significant changes

364

00:13:50,866 --> 00:13:53,533

to the basic concept  
of how we do life support

365

00:13:53,533 --> 00:13:55,366

and how we support  
these missions,

366

00:13:55,366 --> 00:13:57,966

it's unlikely that we will ever  
get to where we need to get,

367

00:13:57,966 --> 00:13:59,900

which is  
a cost-effective mission

368

00:13:59,900 --> 00:14:03,333

to travel and colonize Mars.

369

00:14:03,333 --> 00:14:06,200

So let's talk about that  
for a second: going to Mars.

370

00:14:06,200 --> 00:14:09,100

So let's say it's  
a three-year mission, all right?

371

00:14:09,100 --> 00:14:11,666

That means that your system,  
your life support system,

372

00:14:11,666 --> 00:14:14,166  
has to function for three years

373  
00:14:14,166 --> 00:14:16,400  
with minimum maintenance  
and no failures,

374  
00:14:16,400 --> 00:14:19,566  
because if the life support  
system fails on that mission,

375  
00:14:19,566 --> 00:14:21,000  
you lose the mission.

376  
00:14:21,000 --> 00:14:23,666  
Astronauts die on the mission,  
and the mission is lost, right?

377  
00:14:23,666 --> 00:14:27,466  
So it's a critical function  
of the spacecraft,

378  
00:14:27,466 --> 00:14:29,266  
is to have that function.

379  
00:14:29,266 --> 00:14:31,333  
Now, what we use right now  
are machines.

380  
00:14:31,333 --> 00:14:33,466  
The International Space Station  
is composed

381  
00:14:33,466 --> 00:14:35,200  
of a lot of different machines

382  
00:14:35,200 --> 00:14:38,300  
with pumps and rotating devices  
that all function.

383

00:14:38,300 --> 00:14:39,966

And you all have an appreciation

384

00:14:39,966 --> 00:14:42,066

for reliability

associated with machines.

385

00:14:42,066 --> 00:14:44,066

That's similar

to the world you live in, right?

386

00:14:44,066 --> 00:14:45,900

I mean, you all probably

have cars,

387

00:14:45,900 --> 00:14:47,366

or your parents have cars.

388

00:14:47,366 --> 00:14:49,500

And, you know, cars break down.

389

00:14:49,500 --> 00:14:51,466

There's no guarantee

when you get in that car

390

00:14:51,466 --> 00:14:52,700

and you want to drive somewhere,

391

00:14:52,700 --> 00:14:54,166

that it's gonna get you

to that place.

392

00:14:54,166 --> 00:14:56,466

And you have a AAA card

in case it breaks down.

393

00:14:56,466 --> 00:14:58,433

You could stay at a hotel

or something like that.

394

00:14:58,433 --> 00:15:00,633

But what if that  
wasn't the case?

395

00:15:00,633 --> 00:15:02,100

So let me give you an example,

396

00:15:02,100 --> 00:15:04,333

and I'm gonna give you an  
example through a proposition.

397

00:15:04,333 --> 00:15:05,533

Here's my proposition.

398

00:15:05,533 --> 00:15:08,533

I'm gonna buy everybody here  
a brand-new car,

399

00:15:08,533 --> 00:15:11,033

any kind of car you want,  
all right?

400

00:15:11,033 --> 00:15:13,366

Sounds like a pretty good deal  
so far, right?

401

00:15:13,366 --> 00:15:16,366

But in return for that,  
you have to do something for me.

402

00:15:16,366 --> 00:15:18,033

You have to drive that car.

403

00:15:18,033 --> 00:15:20,200

You have to drive it  
24 hours a day,

404

00:15:20,200 --> 00:15:23,166

seven days a week,  
365 days a year,

405

00:15:23,166 --> 00:15:24,466  
for the next three years.

406

00:15:24,466 --> 00:15:25,800  
That's roughly  
what it would take

407

00:15:25,800 --> 00:15:27,200  
for a Mars mission,

408

00:15:27,200 --> 00:15:29,433  
for a life support system  
to function on a Mars mission.

409

00:15:29,433 --> 00:15:30,533  
You can't take it to the shop

410

00:15:30,533 --> 00:15:32,466  
and have any maintenance  
done to it at all,

411

00:15:32,466 --> 00:15:35,233  
because on a Mars mission  
there's no shop to go to

412

00:15:35,233 --> 00:15:37,000  
to get maintenance done on it.

413

00:15:37,000 --> 00:15:40,400  
And if it breaks down,  
I'm gonna kill you.

414

00:15:40,400 --> 00:15:41,400  
[laughter]

415

00:15:41,400 --> 00:15:42,866

Okay?

416

00:15:42,866 --> 00:15:44,100  
So it sounded like a good deal,

417

00:15:44,100 --> 00:15:46,800  
but not sounding so good  
anymore, is it?

418

00:15:46,800 --> 00:15:48,733  
And that's the problem  
with mechanical devices.

419

00:15:48,733 --> 00:15:51,300  
Mechanical devices break down.

420

00:15:51,300 --> 00:15:54,233  
For a car to drive  
for three years continuously,

421

00:15:54,233 --> 00:15:56,433  
you'd be putting, like,  
500,000 miles on it.

422

00:15:56,433 --> 00:15:58,933  
And we all know there's no way  
your car is gonna drive

423

00:15:58,933 --> 00:16:01,133  
for 500,000 miles  
without breaking down.

424

00:16:01,133 --> 00:16:03,300  
It's just not gonna happen,  
right?

425

00:16:03,300 --> 00:16:04,366  
So I have another proposition,

426

00:16:04,366 --> 00:16:06,433  
hopefully a better proposition  
for you.

427  
00:16:06,433 --> 00:16:07,766  
I'm still gonna get your car,  
don't worry.

428  
00:16:07,766 --> 00:16:09,366  
You're all still  
gonna get your car.

429  
00:16:09,366 --> 00:16:12,233  
And in return for that,  
you have to do something for me.

430  
00:16:12,233 --> 00:16:14,900  
What you have to do is,  
you have to, as a human being,

431  
00:16:14,900 --> 00:16:18,766  
just simply stay alive  
for three years.

432  
00:16:18,766 --> 00:16:19,966  
Right?

433  
00:16:19,966 --> 00:16:21,666  
Just stay alive.

434  
00:16:21,666 --> 00:16:23,166  
I mean,  
even if you've just recently

435  
00:16:23,166 --> 00:16:25,566  
been diagnosed with cancer,  
you could probably eke that out,

436  
00:16:25,566 --> 00:16:28,000  
three years, right?

437

00:16:28,000 --> 00:16:29,633

That's the difference  
between machines

438

00:16:29,633 --> 00:16:31,400

and biological processes.

439

00:16:31,400 --> 00:16:33,100

The level of reliability

440

00:16:33,100 --> 00:16:36,366

is orders of magnitude better  
for human beings.

441

00:16:36,366 --> 00:16:38,400

The average life span  
of a human being

442

00:16:38,400 --> 00:16:41,766

is about 65, 70 years.

443

00:16:41,766 --> 00:16:43,466

The average life span  
of your car,

444

00:16:43,466 --> 00:16:47,233

running continuously,  
is about two years, right?

445

00:16:47,233 --> 00:16:48,600

Why is this?

446

00:16:48,600 --> 00:16:50,666

Well, it's obvious;  
it's evolution, right?

447

00:16:50,666 --> 00:16:52,100

You, as a human being,

448

00:16:52,100 --> 00:16:55,766  
you have over 4 billion years  
of evolution behind you,

449

00:16:55,766 --> 00:16:59,300  
4 billion years of trying  
every different possibility

450

00:16:59,300 --> 00:17:01,900  
and determining what  
is the optimal solution

451

00:17:01,900 --> 00:17:05,600  
to longevity for your particular  
species that you're in.

452

00:17:05,600 --> 00:17:06,666  
Your car has what?

453

00:17:06,666 --> 00:17:08,800  
Generously,  
150 years of evolution.

454

00:17:08,800 --> 00:17:11,133  
That's the Industrial  
Revolution, right?

455

00:17:11,133 --> 00:17:13,700  
So the level of refinement  
that has occurred

456

00:17:13,700 --> 00:17:15,266  
in biological processes

457

00:17:15,266 --> 00:17:17,333  
is an order of magnitude better

458

00:17:17,333 --> 00:17:19,766

than what exists  
in mechanical systems.

459  
00:17:19,766 --> 00:17:21,500

So if we can take  
the lessons learned

460  
00:17:21,500 --> 00:17:23,066  
from the biological process,

461  
00:17:23,066 --> 00:17:26,700  
specifically the lessons learned  
from that evolutionary process,

462  
00:17:26,700 --> 00:17:30,233  
and apply it to the development  
of life support systems,

463  
00:17:30,233 --> 00:17:33,433  
we can achieve much higher  
levels of reliability.

464  
00:17:33,433 --> 00:17:34,666  
All right?

465  
00:17:34,666 --> 00:17:37,433  
So what I need is,  
I need a life support system

466  
00:17:37,433 --> 00:17:38,933  
that's good for three years,

467  
00:17:38,933 --> 00:17:43,200  
guaranteed will not break down,  
no maintenance required for it.

468  
00:17:43,200 --> 00:17:44,666  
Right?

469

00:17:44,666 --> 00:17:47,466

Hey, if I can do three years,  
I can probably do five years.

470

00:17:47,466 --> 00:17:50,133

If I could do five years,  
I could probably do ten years.

471

00:17:50,133 --> 00:17:51,433

And if I could do ten years,

472

00:17:51,433 --> 00:17:54,733

I could probably do  
20, 30 years out of it, right?

473

00:17:54,733 --> 00:17:56,800

So, with that proposition,  
the question is,

474

00:17:56,800 --> 00:17:58,300

is that at all possible?

475

00:17:58,300 --> 00:18:03,533

Or am I just, you know,  
chasing at stars here on this?

476

00:18:03,533 --> 00:18:07,166

Are there any examples of water  
recycling systems out there

477

00:18:07,166 --> 00:18:08,633

that have  
that kind of longevity?

478

00:18:08,633 --> 00:18:10,466

Are there any  
water recycling systems

479

00:18:10,466 --> 00:18:13,633

that are good for 80 years,

no maintenance,

480

00:18:13,633 --> 00:18:15,466

you never have to do  
anything with them,

481

00:18:15,466 --> 00:18:19,333

and they work perfectly  
for that period of time?

482

00:18:19,333 --> 00:18:22,466

Nobody knows of any?

483

00:18:22,466 --> 00:18:23,466

Please.

484

00:18:23,466 --> 00:18:24,933

You are all examples

485

00:18:24,933 --> 00:18:26,033

of water recycling systems.

486

00:18:26,033 --> 00:18:27,300

So right answer.

487

00:18:27,300 --> 00:18:30,166

You are all examples  
of water recycling systems.

488

00:18:30,166 --> 00:18:31,833

I guess you guys  
are all planning on living

489

00:18:31,833 --> 00:18:33,700

for probably 80 years.

490

00:18:33,700 --> 00:18:35,933

Your small intestine  
takes everything you drink,

491

00:18:35,933 --> 00:18:37,300

all of the water,

492

00:18:37,300 --> 00:18:41,600

separates out any bad bacteria,  
viruses, any contaminants,

493

00:18:41,600 --> 00:18:43,266

allows the water  
to pass through--

494

00:18:43,266 --> 00:18:45,400

and other things that  
are necessary for your body--

495

00:18:45,400 --> 00:18:47,000

into your blood.

496

00:18:47,000 --> 00:18:49,166

There's no maintenance  
on your small intestine.

497

00:18:49,166 --> 00:18:51,933

There's no such thing as small  
intestine replacement surgery.

498

00:18:51,933 --> 00:18:53,066

You don't go into the shop

499

00:18:53,066 --> 00:18:55,100

to get it tuned up  
every once in a while.

500

00:18:55,100 --> 00:18:57,333

It just works  
incredibly reliably.

501

00:18:57,333 --> 00:18:58,700

And it works reliably

502

00:18:58,700 --> 00:19:02,266  
because that evolutionary  
process has driven it that.

503

00:19:02,266 --> 00:19:05,100  
And what it's taught us is that  
massively parallel systems

504

00:19:05,100 --> 00:19:07,600  
and targeted regenerability  
are the key,

505

00:19:07,600 --> 00:19:12,000  
particularly for water recycling  
and the small intestine system.

506

00:19:12,000 --> 00:19:14,800  
So there are two applications  
that we primarily look at.

507

00:19:14,800 --> 00:19:16,600  
One of them, of course,  
is the small intestine

508

00:19:16,600 --> 00:19:17,800  
in the human body.

509

00:19:17,800 --> 00:19:19,766  
The other one  
is plant root zones.

510

00:19:19,766 --> 00:19:21,666  
You know, there are trees  
in California

511

00:19:21,666 --> 00:19:24,400  
that grow  
for thousands of years.

512

00:19:24,400 --> 00:19:26,166

They grow in dirt.

513

00:19:26,166 --> 00:19:27,900

I mean, what kind  
of water recycling system

514

00:19:27,900 --> 00:19:31,000

can you pour dirt into  
and it's not gonna clog it up?

515

00:19:31,000 --> 00:19:32,400

I mean, there are none.

516

00:19:32,400 --> 00:19:35,333

None that we've manufactured  
have that capability.

517

00:19:35,333 --> 00:19:37,200

But plants have that capability.

518

00:19:37,200 --> 00:19:39,066

You know, they have  
extremely long lives,

519

00:19:39,066 --> 00:19:41,400

live in an environment  
where they can't move.

520

00:19:41,400 --> 00:19:42,633

No matter what happens,

521

00:19:42,633 --> 00:19:45,566

they have to adapt to it  
and survive through that.

522

00:19:45,566 --> 00:19:47,666

And the key, of course,

is the root zones,

523

00:19:47,666 --> 00:19:50,333

the membranes that exist  
inside the root zones.

524

00:19:50,333 --> 00:19:52,166

In the small intestine,  
the same thing.

525

00:19:52,166 --> 00:19:54,400

The key to the functionality,  
the key to the reliability

526

00:19:54,400 --> 00:19:57,366

is the membranes that exist  
in your small intestine.

527

00:19:57,366 --> 00:19:58,533

All right?

528

00:19:58,533 --> 00:19:59,833

Now, that process--

529

00:19:59,833 --> 00:20:01,900

let's talk a little bit  
about the small intestine,

530

00:20:01,900 --> 00:20:03,766

because it's a little more  
than just membranes

531

00:20:03,766 --> 00:20:04,966

that's going on there.

532

00:20:04,966 --> 00:20:07,300

There's also a technique  
called forward osmosis.

533

00:20:07,300 --> 00:20:09,466

It's really extremely important  
to how your body works

534

00:20:09,466 --> 00:20:11,266

and how your  
small intestine works.

535

00:20:11,266 --> 00:20:13,333

And you guys have probably  
heard of forward osmosis.

536

00:20:13,333 --> 00:20:15,933

That's like Biology I class  
in high school.

537

00:20:15,933 --> 00:20:18,333

You probably learned about it,  
but maybe you forgot about it.

538

00:20:18,333 --> 00:20:20,500

So I'm just gonna give you  
a little bit of a tutorial

539

00:20:20,500 --> 00:20:22,333

on what forward osmosis is.

540

00:20:22,333 --> 00:20:24,466

So, you know, you drink water.

541

00:20:24,466 --> 00:20:26,000

That goes into  
your small intestine.

542

00:20:26,000 --> 00:20:27,400

On the other side  
of your small intestine

543

00:20:27,400 --> 00:20:28,633

is blood, right?

544

00:20:28,633 --> 00:20:29,833

And the water has to move

545

00:20:29,833 --> 00:20:32,866

from your intestine

into the blood, right?

546

00:20:32,866 --> 00:20:34,733

The way that works

is because your blood

547

00:20:34,733 --> 00:20:37,633

has a higher osmotic potential

than what you're drinking.

548

00:20:37,633 --> 00:20:40,733

That's why, if you're ever

lost at sea in a raft,

549

00:20:40,733 --> 00:20:42,833

they tell you,

"Don't drink salt water,"

550

00:20:42,833 --> 00:20:44,633

because salt water

has a higher osmotic potential

551

00:20:44,633 --> 00:20:45,966

than your blood,

552

00:20:45,966 --> 00:20:47,833

and so it'll cause the process

to work backwards.

553

00:20:47,833 --> 00:20:49,200

You'll take the water

out of your blood,

554

00:20:49,200 --> 00:20:50,833

and it'll go into  
your small intestine,

555

00:20:50,833 --> 00:20:53,466

and then you'll become  
even more dehydrated.

556

00:20:53,466 --> 00:20:54,933

So what's  
this osmotic potential?

557

00:20:54,933 --> 00:20:57,100

This magic osmotic potential,  
right?

558

00:20:57,100 --> 00:20:58,400

It's a water recycling system

559

00:20:58,400 --> 00:20:59,800

that doesn't need  
any electricity

560

00:20:59,800 --> 00:21:00,966

or any pumps or anything.

561

00:21:00,966 --> 00:21:02,833

It just kind of works, right?

562

00:21:02,833 --> 00:21:04,500

And I'll give you  
an example of it.

563

00:21:04,500 --> 00:21:05,766

So if I had a glass of water,

564

00:21:05,766 --> 00:21:07,633

I set the glass of water  
right here,

565

00:21:07,633 --> 00:21:09,733

and I filled it up  
with tap water,

566

00:21:09,733 --> 00:21:12,000

and then I took a shot glass  
of salt water

567

00:21:12,000 --> 00:21:14,533

and carefully poured  
the shot glass of salt water

568

00:21:14,533 --> 00:21:16,866

into the larger cup  
of fresh water,

569

00:21:16,866 --> 00:21:18,300

and then just left it there--

570

00:21:18,300 --> 00:21:19,900

those are the kind  
of experiments I like,

571

00:21:19,900 --> 00:21:21,233

ones where you don't  
do anything,

572

00:21:21,233 --> 00:21:23,666

you just go away, have lunch,  
come back later--

573

00:21:23,666 --> 00:21:26,366

I would no longer have  
a ball of salt water

574

00:21:26,366 --> 00:21:28,266

inside the fresh water  
anymore, right?

575

00:21:28,266 --> 00:21:29,633  
It would evenly mix,

576  
00:21:29,633 --> 00:21:32,200  
and I'd just have salty water  
inside there, right?

577  
00:21:32,200 --> 00:21:34,733  
And that's driven by a process  
called entropy.

578  
00:21:34,733 --> 00:21:38,166  
Entropy guides everything  
that occurs in the universe.

579  
00:21:38,166 --> 00:21:41,966  
Basically what it states is that  
it takes work to make order,

580  
00:21:41,966 --> 00:21:45,033  
and then things naturally go  
from order to disorder.

581  
00:21:45,033 --> 00:21:46,466  
And entropy is a measurement

582  
00:21:46,466 --> 00:21:50,900  
of the rate at which they go  
from order to disorder.

583  
00:21:50,900 --> 00:21:52,200  
So when you guys were kids

584  
00:21:52,200 --> 00:21:53,966  
and your parents would scream  
and yell at you

585  
00:21:53,966 --> 00:21:55,400  
and tell you to go  
clean up your room,

586

00:21:55,400 --> 00:21:56,966  
and you would go  
and clean up your room.

587

00:21:56,966 --> 00:21:58,666  
They'd come back there  
a couple days later,

588

00:21:58,666 --> 00:22:01,166  
mad at you, saying you didn't  
clean up your room.

589

00:22:01,166 --> 00:22:02,833  
You were right; they were wrong.

590

00:22:02,833 --> 00:22:04,533  
You cannot keep a room clean.

591

00:22:04,533 --> 00:22:07,533  
It is actually impossible  
to keep a room clean.

592

00:22:07,533 --> 00:22:09,533  
You can't do it, all right?

593

00:22:09,533 --> 00:22:11,600  
So let's go back  
to my glass example.

594

00:22:11,600 --> 00:22:14,533  
Now, if I take my cup and  
I separate it into two halves,

595

00:22:14,533 --> 00:22:17,466  
I put a membrane separating  
the cup into two halves.

596

00:22:17,466 --> 00:22:20,133

On one side, I put fresh water.

597

00:22:20,133 --> 00:22:21,833

On the other side,  
I put salt water.

598

00:22:21,833 --> 00:22:23,566

And the membrane  
is a special membrane.

599

00:22:23,566 --> 00:22:25,666

The membrane will allow  
water to pass,

600

00:22:25,666 --> 00:22:27,533

but it will not allow salts

601

00:22:27,533 --> 00:22:29,133

or anything else  
to pass across it.

602

00:22:29,133 --> 00:22:30,866

It's basically  
your small intestine.

603

00:22:30,866 --> 00:22:33,500

If I took your small intestine  
and glued it into a cup,

604

00:22:33,500 --> 00:22:36,900

put water on one side,  
salt water on the other side,

605

00:22:36,900 --> 00:22:39,000

set it there, left it there,  
went to lunch,

606

00:22:39,000 --> 00:22:40,500

came back two hours later,

607  
00:22:40,500 --> 00:22:41,600  
what would happen--

608  
00:22:41,600 --> 00:22:42,900  
because entropy's real, right?

609  
00:22:42,900 --> 00:22:43,900  
Can't change it.

610  
00:22:43,900 --> 00:22:45,400  
Something has to happen here.

611  
00:22:45,400 --> 00:22:49,066  
All the fresh water will go from  
the fresh water side of the cup

612  
00:22:49,066 --> 00:22:51,833  
over to the salt water side  
of the cup.

613  
00:22:51,833 --> 00:22:54,266  
That's what's shown  
in this diagram.

614  
00:22:54,266 --> 00:22:57,866  
So we start off with tap water  
and salt water, equal heights.

615  
00:22:57,866 --> 00:23:00,266  
Membrane separating  
between the two of them.

616  
00:23:00,266 --> 00:23:01,466  
Let it sit for a while.

617  
00:23:01,466 --> 00:23:03,633  
Virtually all  
the fresh water's gonna go

618

00:23:03,633 --> 00:23:04,966

and dilute out the salt water.

619

00:23:04,966 --> 00:23:09,100

Salt water is gonna raise  
in height

620

00:23:09,100 --> 00:23:13,000

equal to the amount of water  
that passes across it.

621

00:23:13,000 --> 00:23:15,800

And that's actually  
a way of measuring entropy.

622

00:23:15,800 --> 00:23:17,866

It's a very simple experiment  
to measure entropy.

623

00:23:17,866 --> 00:23:19,300

And I joke  
about small intestines,

624

00:23:19,300 --> 00:23:21,000

but some of the earliest  
entropy tables--

625

00:23:21,000 --> 00:23:22,600

and any of you who are engineers

626

00:23:22,600 --> 00:23:24,433

have worked  
with entropy tables before--

627

00:23:24,433 --> 00:23:25,800

were actually generated  
that way,

628

00:23:25,800 --> 00:23:27,066

because it's an easy  
experiment to do.

629  
00:23:27,066 --> 00:23:28,100  
All you need is a ruler

630  
00:23:28,100 --> 00:23:29,633  
to measure the change  
in entropy.

631  
00:23:29,633 --> 00:23:31,766  
And they did, in fact,  
use small intestines,

632  
00:23:31,766 --> 00:23:33,366  
calf intestines  
and things like that,

633  
00:23:33,366 --> 00:23:34,533  
to run that experiment.

634  
00:23:34,533 --> 00:23:36,666  
It's a very well known  
experiment.

635  
00:23:36,666 --> 00:23:39,566  
The other important part  
of this forward osmosis concept

636  
00:23:39,566 --> 00:23:42,033  
is this membrane,  
this little black line.

637  
00:23:42,033 --> 00:23:43,866  
Looks pretty simple  
when it's a little black line,

638  
00:23:43,866 --> 00:23:45,033  
but it actually turns out

639

00:23:45,033 --> 00:23:46,766

it's a lot more complicated  
than that.

640

00:23:46,766 --> 00:23:50,833

In your body, your small  
intestine is made out of lipids.

641

00:23:50,833 --> 00:23:52,866

As a matter of fact,  
you're made out lipids.

642

00:23:52,866 --> 00:23:54,333

Your skin is lipids.

643

00:23:54,333 --> 00:23:57,033

All the membranes  
in your cells are lipids.

644

00:23:57,033 --> 00:23:59,200

Your small intestine is lipids.

645

00:23:59,200 --> 00:24:01,500

Lipids are a naturally  
produced molecule

646

00:24:01,500 --> 00:24:03,333

that's produced  
by mammalian cells

647

00:24:03,333 --> 00:24:06,600

and other types of bacteria.

648

00:24:06,600 --> 00:24:07,766

A lipid has two tails.

649

00:24:07,766 --> 00:24:09,766

It has a head group,  
hydrophylic head group.

650

00:24:09,766 --> 00:24:12,233

That means that the head group likes to be in water.

651

00:24:12,233 --> 00:24:14,400

And it has a hydrophobic tail group,

652

00:24:14,400 --> 00:24:17,500

which means the tail group does not like to be in water.

653

00:24:17,500 --> 00:24:20,300

A cousin of the lipid is the fatty acid.

654

00:24:20,300 --> 00:24:22,100

The fatty acid only has one tail group.

655

00:24:22,100 --> 00:24:23,333

It doesn't have two tail groups.

656

00:24:23,333 --> 00:24:24,800

But it does have a head as well.

657

00:24:24,800 --> 00:24:28,300

And it has a similar hydrophobic hydrophilic characteristic.

658

00:24:28,300 --> 00:24:29,900

These characteristics mean that,

659

00:24:29,900 --> 00:24:31,700

if you look at this picture on the bottom here,

660

00:24:31,700 --> 00:24:33,900

if I take a bunch  
of these molecules

661  
00:24:33,900 --> 00:24:36,266  
and put them  
into a cup of water,

662  
00:24:36,266 --> 00:24:38,000  
the head groups  
are gonna face out,

663  
00:24:38,000 --> 00:24:39,766  
and the tail groups  
are gonna face together,

664  
00:24:39,766 --> 00:24:40,866  
because the tail groups

665  
00:24:40,866 --> 00:24:42,800  
don't want to be  
in contact with water,

666  
00:24:42,800 --> 00:24:46,700  
which means it's gonna naturally  
form a lipid bilayer, right?

667  
00:24:46,700 --> 00:24:48,266  
And you're made  
of lipid bilayers.

668  
00:24:48,266 --> 00:24:49,833  
Your skin is a lipid bilayer.

669  
00:24:49,833 --> 00:24:52,233  
Your small intestine  
is a lipid bilayer.

670  
00:24:52,233 --> 00:24:55,400  
The paint you put on your house  
is a lipid bilayer.

671

00:24:55,400 --> 00:24:57,566

Lipid bilayers are ubiquitous  
around you,

672

00:24:57,566 --> 00:24:59,800

in products you buy  
and in everything.

673

00:24:59,800 --> 00:25:00,866

And you've all seen it.

674

00:25:00,866 --> 00:25:02,033

Take a little bit of soap.

675

00:25:02,033 --> 00:25:03,300

Soap's made of lipids.

676

00:25:03,300 --> 00:25:05,733

Take a little soap,  
put it on a glass of water,

677

00:25:05,733 --> 00:25:06,800

and you'll see it spread out

678

00:25:06,800 --> 00:25:08,266

across the top  
of the glass of water.

679

00:25:08,266 --> 00:25:09,766

It's making a lipid bilayer  
on it.

680

00:25:09,766 --> 00:25:11,233

One of the great things  
about these--

681

00:25:11,233 --> 00:25:13,066

and very important

for your small intestine--

682

00:25:13,066 --> 00:25:15,933

is that if you rip  
that lipid bilayer open,

683

00:25:15,933 --> 00:25:17,500

it's just gonna reseal itself.

684

00:25:17,500 --> 00:25:18,500

It's gonna grow.

685

00:25:18,500 --> 00:25:19,800

It's gonna regenerate itself.

686

00:25:19,800 --> 00:25:21,666

In your body,  
in your small intestines,

687

00:25:21,666 --> 00:25:23,033

there's mammalian cells

688

00:25:23,033 --> 00:25:25,166

that are on the back side  
of the small intestine

689

00:25:25,166 --> 00:25:26,800

that hyperexpress lipids.

690

00:25:26,800 --> 00:25:29,166

So the membrane itself  
is soaking in lipids,

691

00:25:29,166 --> 00:25:30,533

and fatty acids as well.

692

00:25:30,533 --> 00:25:32,933

Fatty acids turn out to be  
extremely important as well.

693

00:25:32,933 --> 00:25:35,366

So your small intestine  
is a regenerative membrane.

694

00:25:35,366 --> 00:25:37,400

It's a membrane that,  
when it gets damaged,

695

00:25:37,400 --> 00:25:38,833

it can repair itself.

696

00:25:38,833 --> 00:25:41,233

The fatty acids  
provide some protection to it.

697

00:25:41,233 --> 00:25:43,900

So it means when you eat  
something, consume something,

698

00:25:43,900 --> 00:25:46,266

if it forms a solid that's  
gonna stick to the membrane,

699

00:25:46,266 --> 00:25:48,400

it's gonna stick  
to the fatty acid coating

700

00:25:48,400 --> 00:25:50,000

before it's gonna stick  
to the membrane,

701

00:25:50,000 --> 00:25:51,866

and the fatty acids  
will just wash off

702

00:25:51,866 --> 00:25:53,666

as part of the bacteria.

703

00:25:53,666 --> 00:25:55,300

So that's what we want  
to develop, right?

704

00:25:55,300 --> 00:25:57,000

We want to develop  
a water recycling system

705

00:25:57,000 --> 00:25:58,566

that simulates  
the small intestine.

706

00:25:58,566 --> 00:26:01,233

And that's the key aspect  
of the small intestine

707

00:26:01,233 --> 00:26:03,200

that provides its longevity,

708

00:26:03,200 --> 00:26:08,266

its 80-plus, 90-year life  
that's associated with it.

709

00:26:08,266 --> 00:26:09,500

So here's a pictorial

710

00:26:09,500 --> 00:26:12,133

that kind of shows  
how this process would work.

711

00:26:12,133 --> 00:26:14,300

So down here we have a solution.

712

00:26:14,300 --> 00:26:16,633

In this solution,  
we've taken E. coli,

713

00:26:16,633 --> 00:26:18,866

and we've genetically engineered  
the E. coli

714

00:26:18,866 --> 00:26:23,266  
so that the E. coli are  
hyperexpressing fatty acids--

715

00:26:23,266 --> 00:26:26,000  
these are the fatty acids--  
and also lipids as well.

716

00:26:26,000 --> 00:26:27,900  
We use E. coli  
rather than mammalian cells,

717

00:26:27,900 --> 00:26:29,700  
because mammalian cells  
are very hard to grow

718

00:26:29,700 --> 00:26:32,233  
and E. coli is almost  
impossible to kill.

719

00:26:32,233 --> 00:26:34,866  
So it makes it a lot easier.

720

00:26:34,866 --> 00:26:38,333  
So the lipids, then, can replace  
any damage that occurs.

721

00:26:38,333 --> 00:26:39,666  
This is the lipid bilayer here,

722

00:26:39,666 --> 00:26:42,500  
so this would be  
the actual membrane itself.

723

00:26:42,500 --> 00:26:44,966  
And if there's any damage  
to this lipid membrane,

724

00:26:44,966 --> 00:26:46,100  
the lipids in the solution

725  
00:26:46,100 --> 00:26:48,033  
can replace  
the missing lipids in there.

726  
00:26:48,033 --> 00:26:50,000  
But more important than that  
are the fatty acids.

727  
00:26:50,000 --> 00:26:52,066  
The fatty acids are permeable

728  
00:26:52,066 --> 00:26:54,166  
through this lipid bilayer  
membrane.

729  
00:26:54,166 --> 00:26:55,966  
And so when  
they're on this side,

730  
00:26:55,966 --> 00:26:57,333  
we modify this solution

731  
00:26:57,333 --> 00:26:59,833  
so we have a high solubility  
of fatty acids.

732  
00:26:59,833 --> 00:27:01,566  
When they permeate  
through the membrane

733  
00:27:01,566 --> 00:27:02,833  
into the feed solution,

734  
00:27:02,833 --> 00:27:04,566  
they have a very low solubility.

735

00:27:04,566 --> 00:27:07,900  
So they form a solid phase  
on the surface of the membrane.

736  
00:27:07,900 --> 00:27:09,333  
This is like a sacrificial--

737  
00:27:09,333 --> 00:27:13,233  
biologically sacrificial coating  
on the surface of the membranes.

738  
00:27:13,233 --> 00:27:16,600  
So if, for instance, radiation  
in space attacks the water,

739  
00:27:16,600 --> 00:27:18,166  
produces hydroxyl radicals

740  
00:27:18,166 --> 00:27:20,866  
that would oxidize the membrane  
and damage the membrane.

741  
00:27:20,866 --> 00:27:22,866  
They're gonna damage  
the fatty acids layer

742  
00:27:22,866 --> 00:27:25,266  
before they damage  
the lipid layer.

743  
00:27:25,266 --> 00:27:27,600  
If anything is gonna  
precipitate out, shown here,

744  
00:27:27,600 --> 00:27:29,233  
they're gonna attach themselves

745  
00:27:29,233 --> 00:27:33,766  
to the actual fatty acid layer  
rather than the lipid layer,

746

00:27:33,766 --> 00:27:35,800  
and then the flow of fluid  
across the top

747

00:27:35,800 --> 00:27:37,100  
strips off the fatty acids.

748

00:27:37,100 --> 00:27:38,933  
When the fatty acids  
are stripped off,

749

00:27:38,933 --> 00:27:41,366  
then more fatty acids  
permeate through the membrane

750

00:27:41,366 --> 00:27:42,466  
to replace those.

751

00:27:42,466 --> 00:27:44,066  
So that's the basis  
of the concept

752

00:27:44,066 --> 00:27:45,500  
of this regeneral membrane.

753

00:27:45,500 --> 00:27:48,900  
It pretty much follows the way  
your small intestine works.

754

00:27:48,900 --> 00:27:51,300  
At least it follows  
sort of the lessons learned

755

00:27:51,300 --> 00:27:52,866  
of how your  
small intestine works.

756

00:27:52,866 --> 00:27:55,233

It's not exactly the same  
as your small intestine,

757

00:27:55,233 --> 00:27:58,366

but the idea is that it mimics  
that regenerable capability.

758

00:27:58,366 --> 00:28:00,300

It's taking the lessons learned

759

00:28:00,300 --> 00:28:02,000

from that  
evolutionary development

760

00:28:02,000 --> 00:28:03,200

of your small intestine,

761

00:28:03,200 --> 00:28:06,566

and applying it  
to a mechanical system.

762

00:28:06,566 --> 00:28:07,800

So just kind of a summary.

763

00:28:07,800 --> 00:28:10,300

We actually have  
a water recycling process

764

00:28:10,300 --> 00:28:11,600

that we utilize that in,

765

00:28:11,600 --> 00:28:13,733

and that's  
this system right here.

766

00:28:13,733 --> 00:28:16,533

So the way this works,  
this osmotic agent loop

767

00:28:16,533 --> 00:28:18,066  
is where the bacteria grow.

768  
00:28:18,066 --> 00:28:20,766  
So the genetically engineered  
bacteria are in this loop.

769  
00:28:20,766 --> 00:28:22,766  
The feed, which is urine  
and humidity condensate,

770  
00:28:22,766 --> 00:28:24,233  
is on the other side.

771  
00:28:24,233 --> 00:28:26,133  
And this is the biomembrane  
right here.

772  
00:28:26,133 --> 00:28:27,933  
The red would be  
the biomembrane.

773  
00:28:27,933 --> 00:28:31,000  
So the fatty acids are applied  
to this side of the membrane,

774  
00:28:31,000 --> 00:28:32,900  
and then the genetically  
engineered bacteria

775  
00:28:32,900 --> 00:28:33,900  
are on the other side.

776  
00:28:33,900 --> 00:28:35,366  
So this solution is very high

777  
00:28:35,366 --> 00:28:37,633  
in concentration in lipids  
and fatty acids,

778

00:28:37,633 --> 00:28:40,800

and the lipids and fatty acids  
permeate across the membrane

779

00:28:40,800 --> 00:28:43,566

in here and provide  
a protective coating to it.

780

00:28:43,566 --> 00:28:47,100

So that's the synthetic  
biological membrane technology.

781

00:28:47,100 --> 00:28:48,433

Now, there are other lessons

782

00:28:48,433 --> 00:28:50,800

that we've learned from  
the International Space Station

783

00:28:50,800 --> 00:28:52,666

that also have taken us  
in this direction

784

00:28:52,666 --> 00:28:55,000

of using the experience  
of evolution

785

00:28:55,000 --> 00:28:56,466

to resolve our problems.

786

00:28:56,466 --> 00:28:58,500

And I'm gonna talk  
about two of those here

787

00:28:58,500 --> 00:28:59,900

for the rest  
of the presentation.

788

00:28:59,900 --> 00:29:01,133

One of them deals with,

789

00:29:01,133 --> 00:29:03,266

when you have a closed  
spacecraft environment,

790

00:29:03,266 --> 00:29:05,000

things build up  
in that environment.

791

00:29:05,000 --> 00:29:06,200

Trace contaminants,

792

00:29:06,200 --> 00:29:07,433

contaminants that  
you didn't even know

793

00:29:07,433 --> 00:29:08,766

existed in that environment,

794

00:29:08,766 --> 00:29:10,633

over very long periods of time,

795

00:29:10,633 --> 00:29:12,400

if they don't have a method  
of being removed,

796

00:29:12,400 --> 00:29:14,566

they're gonna build up  
in the spacecraft cabin.

797

00:29:14,566 --> 00:29:16,833

And we're gonna talk about  
some of those applications.

798

00:29:16,833 --> 00:29:18,766

And then the other one  
deals with this issue

799

00:29:18,766 --> 00:29:20,633  
of things precipitating out,

800

00:29:20,633 --> 00:29:23,433  
and the problems associated  
with astronaut bone loss

801

00:29:23,433 --> 00:29:27,733  
and the impact that that has  
on water recycling systems.

802

00:29:27,733 --> 00:29:30,000  
Okay, so one of the projects  
that we're working on

803

00:29:30,000 --> 00:29:31,933  
is dealing with the  
International Space Station,

804

00:29:31,933 --> 00:29:33,900  
a failure of  
the International Space Station

805

00:29:33,900 --> 00:29:36,233  
water recycling system  
to be able to remove

806

00:29:36,233 --> 00:29:38,533  
a particular trace contaminant  
that's building up

807

00:29:38,533 --> 00:29:40,800  
in the space environment.

808

00:29:40,800 --> 00:29:43,166  
It actually exists  
in the air environment.

809

00:29:43,166 --> 00:29:44,600  
That's where it's coming from.

810

00:29:44,600 --> 00:29:46,733

It's coming in through  
the condensing heat exchanger

811

00:29:46,733 --> 00:29:48,500

and getting into  
the water treatment system.

812

00:29:48,500 --> 00:29:53,600

And this is a plot showing  
from 2010 all the way to 2016,

813

00:29:53,600 --> 00:29:56,800

looking at total  
organic carbon content

814

00:29:56,800 --> 00:29:59,366

of the output of what's called  
a multi-filtration bed.

815

00:29:59,366 --> 00:30:00,700

And as you can see,

816

00:30:00,700 --> 00:30:03,666

normally we have very low  
concentration of organics,

817

00:30:03,666 --> 00:30:04,966

but then every once  
in a while,

818

00:30:04,966 --> 00:30:07,200

we have these events  
that are occurring

819

00:30:07,200 --> 00:30:12,333

that are causing contaminants  
to appear in high concentrations

820

00:30:12,333 --> 00:30:14,000

and occasionally exceed

821

00:30:14,000 --> 00:30:17,466

our minimal acceptable level  
for the product water quality.

822

00:30:17,466 --> 00:30:20,000

And what's happening here  
is that we have this compound,

823

00:30:20,000 --> 00:30:22,466

it's in a very,  
very low concentration,

824

00:30:22,466 --> 00:30:24,933

but one of the technologies  
in the ISS system

825

00:30:24,933 --> 00:30:26,500

is an absorption bed,

826

00:30:26,500 --> 00:30:28,466

and it builds up  
these compounds on it,

827

00:30:28,466 --> 00:30:31,333

and then eventually  
it desorbs those compounds,

828

00:30:31,333 --> 00:30:33,366

and that's why we see  
these peaks coming out.

829

00:30:33,366 --> 00:30:35,500

And so what we want to do is,  
we want to get a technology

830

00:30:35,500 --> 00:30:38,833

that will allow us to remove these compounds out of there.

831

00:30:38,833 --> 00:30:41,000

So this is a flow diagram of the ISS system.

832

00:30:41,000 --> 00:30:43,333

Remember I was referring to these multi-filtration beds.

833

00:30:43,333 --> 00:30:46,233

So water comes in here, goes through a filter,

834

00:30:46,233 --> 00:30:47,833

goes through this multi-filtration bed,

835

00:30:47,833 --> 00:30:49,700

then it goes through this catalytic reactor

836

00:30:49,700 --> 00:30:50,700

that oxidizes it.

837

00:30:50,700 --> 00:30:51,766

And the problem is,

838

00:30:51,766 --> 00:30:53,300

this multi-filtration bed is failing

839

00:30:53,300 --> 00:30:54,933

over long periods of time.

840

00:30:54,933 --> 00:30:57,433

So the approach is to replace those multi-filtration beds

841  
00:30:57,433 --> 00:30:58,766  
with a biomembrane,

842  
00:30:58,766 --> 00:31:01,966  
with a biological membrane  
to fix that.

843  
00:31:01,966 --> 00:31:03,300  
And we're using a technique--

844  
00:31:03,300 --> 00:31:06,300  
a membrane called  
an aquaporin membrane.

845  
00:31:06,300 --> 00:31:07,800  
It's very similar  
to the membrane

846  
00:31:07,800 --> 00:31:08,800  
I just described to you.

847  
00:31:08,800 --> 00:31:10,100  
It's a lipid-based membrane,

848  
00:31:10,100 --> 00:31:11,600  
but it has a protein  
embedded in it

849  
00:31:11,600 --> 00:31:13,500  
called an aquaporin protein.

850  
00:31:13,500 --> 00:31:16,100  
And you guys are all based  
on aquaporin proteins.

851  
00:31:16,100 --> 00:31:18,866  
Aquaporin proteins  
are how your kidneys work

852

00:31:18,866 --> 00:31:21,266

in separating water  
from your blood.

853

00:31:21,266 --> 00:31:23,233

They're key  
in your cellular function

854

00:31:23,233 --> 00:31:26,266

for increased flux,  
water channels in cells.

855

00:31:26,266 --> 00:31:29,166

They're commonly found  
in root zones of plants as well,

856

00:31:29,166 --> 00:31:32,200

to accelerate water transport  
across membranes.

857

00:31:32,200 --> 00:31:33,933

It's a very unique protein,

858

00:31:33,933 --> 00:31:35,600

because it's charged  
in the center.

859

00:31:35,600 --> 00:31:37,500

It has a positive charge  
in the center.

860

00:31:37,500 --> 00:31:39,233

So that means  
that any sort of salts

861

00:31:39,233 --> 00:31:41,700

or charged molecules  
that pass through that,

862

00:31:41,700 --> 00:31:43,800  
you'd have to get both charges  
to go through.

863  
00:31:43,800 --> 00:31:46,433  
You'd have to get the positive  
and the negative to go through.

864  
00:31:46,433 --> 00:31:48,533  
And you can't get the positive  
to go through,

865  
00:31:48,533 --> 00:31:50,300  
because the center  
of the protein

866  
00:31:50,300 --> 00:31:52,066  
has a positive charge  
associated with it.

867  
00:31:52,066 --> 00:31:53,700  
So water can pass through it.

868  
00:31:53,700 --> 00:31:55,266  
Salts can't pass through it.

869  
00:31:55,266 --> 00:31:58,866  
Any organic acids or any  
organics that have a charge

870  
00:31:58,866 --> 00:32:00,166  
can't pass through it,

871  
00:32:00,166 --> 00:32:01,366  
even if they're small enough

872  
00:32:01,366 --> 00:32:05,000  
to pass through  
the pore in the system.

873

00:32:05,000 --> 00:32:06,966

The Nobel Prize  
was actually awarded

874

00:32:06,966 --> 00:32:08,966

to the person who found this  
in 2013.

875

00:32:08,966 --> 00:32:11,033

And there have been several  
development activities

876

00:32:11,033 --> 00:32:12,966

that have come  
out of that experience,

877

00:32:12,966 --> 00:32:15,066

and one of them  
is developing membrane space

878

00:32:15,066 --> 00:32:17,333

with these aquaporin proteins  
into it.

879

00:32:17,333 --> 00:32:19,633

So we've been working with these  
proteins for some time now.

880

00:32:19,633 --> 00:32:22,100

This actually shows what the  
membranes actually look like.

881

00:32:22,100 --> 00:32:24,900

They're little fibers that  
have been coated with lipids,

882

00:32:24,900 --> 00:32:27,600

and the aquaporin proteins  
are these little contactors.

883

00:32:27,600 --> 00:32:30,566

We've been doing experiments on  
the International Space Station

884

00:32:30,566 --> 00:32:32,766

where we've been taking  
waste water on the space station

885

00:32:32,766 --> 00:32:34,200

and processing through them.

886

00:32:34,200 --> 00:32:36,266

And we've also been doing  
a lot of ground-based work,

887

00:32:36,266 --> 00:32:37,700

simulating the waste water

888

00:32:37,700 --> 00:32:39,400

that's on  
the International Space Station

889

00:32:39,400 --> 00:32:40,766

and processing it through.

890

00:32:40,766 --> 00:32:43,466

Just some typical results.

891

00:32:43,466 --> 00:32:46,700

These are mainly contaminants  
out of the cabin, right?

892

00:32:46,700 --> 00:32:48,400

So they're  
semi-volatile organics.

893

00:32:48,400 --> 00:32:51,266

Normally membranes cannot reject  
semi-volatile contaminants.

894

00:32:51,266 --> 00:32:53,100

It's only with  
these aquaporin proteins

895

00:32:53,100 --> 00:32:56,366

that we can get any rejection  
of semi-volatile contaminants

896

00:32:56,366 --> 00:32:57,633

out of these membranes.

897

00:32:57,633 --> 00:33:00,966

As you can see,  
we have about a 50%--

898

00:33:00,966 --> 00:33:03,866

a 50% reduction  
in the total organic carbon

899

00:33:03,866 --> 00:33:05,166

of the water going through it,

900

00:33:05,166 --> 00:33:06,600

which meets our target

901

00:33:06,600 --> 00:33:09,766

for the downstream  
volatile removal assembly.

902

00:33:09,766 --> 00:33:13,500

And this is the problematic  
compound, DMSD,

903

00:33:13,500 --> 00:33:15,833

that's building up in  
the International Space Station,

904

00:33:15,833 --> 00:33:18,066

and we can really dramatically  
have an impact on that.

905

00:33:18,066 --> 00:33:20,533

It actually rejects DMSD  
very well.

906

00:33:20,533 --> 00:33:22,033

From about 20 parts per million,

907

00:33:22,033 --> 00:33:24,600

we can get it down to around  
1 or 2 parts per million

908

00:33:24,600 --> 00:33:26,966

and hold it there  
pretty reliably.

909

00:33:26,966 --> 00:33:28,333

So that's another example

910

00:33:28,333 --> 00:33:32,066

of basically  
a biological technology

911

00:33:32,066 --> 00:33:33,400

that's been optimized.

912

00:33:33,400 --> 00:33:35,266

That protein,  
the structure of that protein

913

00:33:35,266 --> 00:33:38,333

has been optimized over  
the 4 billion years of life

914

00:33:38,333 --> 00:33:40,166

that it's existed here on earth.

915

00:33:40,166 --> 00:33:42,733

And it is an endpoint  
that is perfectly designed

916

00:33:42,733 --> 00:33:45,100

for doing separations  
of biological fluids.

917

00:33:45,100 --> 00:33:46,566

And, of course,  
on the space station,

918

00:33:46,566 --> 00:33:48,466

our waste water  
is a biological fluid.

919

00:33:48,466 --> 00:33:51,600

And that project is actually  
moving to a flight project.

920

00:33:51,600 --> 00:33:52,633

And so next year it'll be

921

00:33:52,633 --> 00:33:54,033

transferring  
to a flight project,

922

00:33:54,033 --> 00:33:55,500

and then the year after that,

923

00:33:55,500 --> 00:33:57,766

they'll be working to replace  
the multi-filtration beds

924

00:33:57,766 --> 00:33:59,833

on ISS with that technology.

925

00:33:59,833 --> 00:34:02,133

Now, another technology  
that I want to talk about,

926

00:34:02,133 --> 00:34:04,233

that isn't actually  
biological,

927

00:34:04,233 --> 00:34:06,333

but I need to sort of  
set the stage

928

00:34:06,333 --> 00:34:08,833

for another  
biological technology,

929

00:34:08,833 --> 00:34:10,200

deals with a failure that we had

930

00:34:10,200 --> 00:34:11,900

on the International  
Space Station

931

00:34:11,900 --> 00:34:14,000

almost a month  
after we installed

932

00:34:14,000 --> 00:34:16,633

the water recycling system  
on the ISS.

933

00:34:16,633 --> 00:34:19,733

The urine processing system  
actually stopped functioning,

934

00:34:19,733 --> 00:34:22,300

and it stopped functioning  
because there was a compound

935

00:34:22,300 --> 00:34:25,633

that was precipitating out  
in it called calcium sulfate.

936  
00:34:25,633 --> 00:34:27,533  
Calcium sulfate  
comes from the fact

937  
00:34:27,533 --> 00:34:30,033  
that when you take astronauts  
and you put them in space,

938  
00:34:30,033 --> 00:34:31,300  
they lose bone mass.

939  
00:34:31,300 --> 00:34:32,833  
Since they don't have  
the loading

940  
00:34:32,833 --> 00:34:34,366  
that you typically  
have here on earth,

941  
00:34:34,366 --> 00:34:35,766  
they're floating around  
in space,

942  
00:34:35,766 --> 00:34:38,200  
your body automatically  
redistributes calcium

943  
00:34:38,200 --> 00:34:39,766  
in your body,

944  
00:34:39,766 --> 00:34:42,833  
moves bone from your legs  
and moves it up to your head

945  
00:34:42,833 --> 00:34:44,300  
and changes it around.

946  
00:34:44,300 --> 00:34:47,266  
And also, you excrete an awful

lot more calcium in your urine

947

00:34:47,266 --> 00:34:48,966

under those circumstances.

948

00:34:48,966 --> 00:34:50,633

And NASA's a very  
conservative organization,

949

00:34:50,633 --> 00:34:52,400

so we all freak out about that,

950

00:34:52,400 --> 00:34:54,300

and we give them lots  
of calcium supplements

951

00:34:54,300 --> 00:34:56,066

and things like that,  
that do virtually nothing,

952

00:34:56,066 --> 00:34:57,866

because it's  
a regulatory process.

953

00:34:57,866 --> 00:35:00,800

And so all that calcium  
ends up in the urine.

954

00:35:00,800 --> 00:35:04,833

And if it mixes with sulfate  
or carbon dioxide,

955

00:35:04,833 --> 00:35:06,566

it produces calcium sulfate,

956

00:35:06,566 --> 00:35:08,600

calcium carbonate  
as a byproduct,

957

00:35:08,600 --> 00:35:12,200  
and that was a failure mode for  
the ISS water recycling system.

958  
00:35:12,200 --> 00:35:15,166  
So we had to bring that thing  
back down to earth,

959  
00:35:15,166 --> 00:35:17,666  
get a chisel, chip out  
all the calcium out of it,

960  
00:35:17,666 --> 00:35:19,900  
and then re-fly it back up to  
the International Space Station.

961  
00:35:19,900 --> 00:35:21,533  
It cost about \$100 million  
to do that.

962  
00:35:21,533 --> 00:35:22,866  
Very, very expensive.

963  
00:35:22,866 --> 00:35:25,066  
So, needless to say,  
NASA was very interested

964  
00:35:25,066 --> 00:35:27,500  
in developing technologies

965  
00:35:27,500 --> 00:35:28,966  
that would prevent that  
from happening.

966  
00:35:28,966 --> 00:35:30,400  
And so we had a lot of funding

967  
00:35:30,400 --> 00:35:31,866  
to look  
at different technologies.

968

00:35:31,866 --> 00:35:33,466

And this is one  
of the technologies

969

00:35:33,466 --> 00:35:36,300

called electro dialysis  
metathesis.

970

00:35:36,300 --> 00:35:38,833

It allows us to actually  
deal with this calcium issue

971

00:35:38,833 --> 00:35:40,033

and remove it from solution

972

00:35:40,033 --> 00:35:42,700

and prevent it  
from causing problems.

973

00:35:42,700 --> 00:35:45,833

We integrated it with the  
space station urine processor.

974

00:35:45,833 --> 00:35:48,666

That's basically what's  
on the right-hand side there.

975

00:35:48,666 --> 00:35:50,900

And what we did is,  
we turned the system on,

976

00:35:50,900 --> 00:35:52,733

and then we  
ran the urine processor

977

00:35:52,733 --> 00:35:54,133

at very high  
water recovery rates,

978  
00:35:54,133 --> 00:35:55,833  
and then we just tried  
to make it fail,

979  
00:35:55,833 --> 00:35:58,133  
tried to see  
if we could make it fail.

980  
00:35:58,133 --> 00:35:59,866  
These are some  
pictures that show

981  
00:35:59,866 --> 00:36:01,733  
the inside of that system.

982  
00:36:01,733 --> 00:36:03,600  
These discs here  
are the heat transfer surface.

983  
00:36:03,600 --> 00:36:04,766  
And you can see here is with

984  
00:36:04,766 --> 00:36:07,333  
the electro dialysis metathesis  
system off,

985  
00:36:07,333 --> 00:36:09,666  
and you can see the calcium  
scale formation.

986  
00:36:09,666 --> 00:36:11,266  
And then these are a bunch  
of different runs

987  
00:36:11,266 --> 00:36:12,666  
where we had the system on.

988  
00:36:12,666 --> 00:36:16,266  
As you can see, it totally

resolves that calcium problem.

989

00:36:16,266 --> 00:36:19,400

So the basic approach was,  
NASA had this problem.

990

00:36:19,400 --> 00:36:21,366

Problem was  
that these endpoints,

991

00:36:21,366 --> 00:36:24,066

these byproducts  
of treating human waste,

992

00:36:24,066 --> 00:36:25,633

are precipitating  
out of solution.

993

00:36:25,633 --> 00:36:26,700

They're causing problems.

994

00:36:26,700 --> 00:36:28,500

They're causing systems to fail,

995

00:36:28,500 --> 00:36:31,600

and making them have  
to come back to earth,

996

00:36:31,600 --> 00:36:35,300

be repaired, and come up with  
solutions to solve that problem.

997

00:36:35,300 --> 00:36:37,666

Not a good situation if you're  
on your way to mars,

998

00:36:37,666 --> 00:36:40,033

to have those kinds  
of failure modes be apparent.

999

00:36:40,033 --> 00:36:42,066

A much better approach  
is to sort of change

1000

00:36:42,066 --> 00:36:43,766

your entire philosophy

1001

00:36:43,766 --> 00:36:47,200

as to how you would conduct  
one of these systems.

1002

00:36:47,200 --> 00:36:50,000

So this is back,  
another picture of this bone.

1003

00:36:50,000 --> 00:36:52,100

This is astronaut bone,  
basically, is what it is.

1004

00:36:52,100 --> 00:36:53,133

There's two different kinds.

1005

00:36:53,133 --> 00:36:54,133

There's the green kind.

1006

00:36:54,133 --> 00:36:56,100

That's Russian astronaut bone.

1007

00:36:56,100 --> 00:36:57,533

And there's the brown kind.

1008

00:36:57,533 --> 00:37:00,500

That's U.S. astronaut bone  
there.

1009

00:37:00,500 --> 00:37:02,933

It's kind of complicated  
why the colors are different.

1010

00:37:02,933 --> 00:37:06,633

But basically, what this material is, is it's gypsum.

1011

00:37:06,633 --> 00:37:09,133

So mixtures of calcium sulfate and calcium carbonate

1012

00:37:09,133 --> 00:37:10,533

are commonly called gypsum.

1013

00:37:10,533 --> 00:37:12,266

Another word you've probably heard of is wallboard,

1014

00:37:12,266 --> 00:37:15,166

so sheetrock that's used in houses.

1015

00:37:15,166 --> 00:37:17,800

Probably in this room we have sheetrock here, right?

1016

00:37:17,800 --> 00:37:20,400

So on ISS we have developed a system

1017

00:37:20,400 --> 00:37:22,200

where if this material fails,

1018

00:37:22,200 --> 00:37:25,633

it causes the water recycling system to fail.

1019

00:37:25,633 --> 00:37:27,766

However, it's a useful product.

1020

00:37:27,766 --> 00:37:29,933

I mean,

it's a construction material.

1021

00:37:29,933 --> 00:37:32,800

So we're kind of taking  
the wrong approach here.

1022

00:37:32,800 --> 00:37:35,533

Rather than having this endpoint  
be a failure mode,

1023

00:37:35,533 --> 00:37:37,900

we should have this endpoint  
be something of value.

1024

00:37:37,900 --> 00:37:40,000

If you're on your way to Mars,

1025

00:37:40,000 --> 00:37:43,333

the waste that you have is  
the best resource that you have,

1026

00:37:43,333 --> 00:37:44,766

the best material that you have.

1027

00:37:44,766 --> 00:37:46,500

So the more  
you can utilize that waste

1028

00:37:46,500 --> 00:37:48,400

for some beneficial purpose,

1029

00:37:48,400 --> 00:37:50,500

the better off you're gonna be.

1030

00:37:50,500 --> 00:37:52,700

So this is a project  
that was called Water Walls.

1031

00:37:52,700 --> 00:37:54,833

It's funded through  
the NIAC proposal.

1032  
00:37:54,833 --> 00:37:56,500  
And that was  
the objective of this.

1033  
00:37:56,500 --> 00:37:59,733  
It was to take all of those  
human waste byproducts,

1034  
00:37:59,733 --> 00:38:02,800  
all of the nastiest,  
most disgusting byproducts,

1035  
00:38:02,800 --> 00:38:04,766  
the concentrated  
urine byproduct,

1036  
00:38:04,766 --> 00:38:06,366  
the concentrated feces,

1037  
00:38:06,366 --> 00:38:09,100  
all the garbage that's produced  
on space station,

1038  
00:38:09,100 --> 00:38:10,333  
all this bone,

1039  
00:38:10,333 --> 00:38:12,533  
astronaut bone material  
that's been produced,

1040  
00:38:12,533 --> 00:38:13,733  
and turn it into something

1041  
00:38:13,733 --> 00:38:16,100  
that's useful  
for that space mission.

1042

00:38:16,100 --> 00:38:18,400

So the idea was, you have  
an inflatable habitat.

1043

00:38:18,400 --> 00:38:21,200

This is a Bigelow  
inflatable habitat.

1044

00:38:21,200 --> 00:38:24,600

And then you basically  
start off with some water

1045

00:38:24,600 --> 00:38:26,366

and some bags on the walls.

1046

00:38:26,366 --> 00:38:29,066

And as time goes on,  
the astronauts produce waste,

1047

00:38:29,066 --> 00:38:30,966

and the waste  
that the astronauts produce

1048

00:38:30,966 --> 00:38:33,466

is used to convert  
the inflatable structure

1049

00:38:33,466 --> 00:38:35,500

into a rigid structure.

1050

00:38:35,500 --> 00:38:37,033

So this is like  
a living organism.

1051

00:38:37,033 --> 00:38:39,500

It has a birth; it's launched.

1052

00:38:39,500 --> 00:38:40,833

Inflatable structure

is launched.

1053

00:38:40,833 --> 00:38:42,700

The inflatable structure  
is deployed.

1054

00:38:42,700 --> 00:38:44,466

Then this habitat has a life.

1055

00:38:44,466 --> 00:38:46,600

And the life is,  
during the period of time

1056

00:38:46,600 --> 00:38:49,466

that you have astronauts in it  
and they're producing waste,

1057

00:38:49,466 --> 00:38:51,266

and those wastes  
then are filling out

1058

00:38:51,266 --> 00:38:53,566

the construction  
of the entire habitat.

1059

00:38:53,566 --> 00:38:54,966

And then it has a death,

1060

00:38:54,966 --> 00:38:57,100

and the death, of course,  
is when it's all used up.

1061

00:38:57,100 --> 00:38:59,166

All the capacity of the system  
is used up,

1062

00:38:59,166 --> 00:39:02,000

and it just simply becomes  
an enclosed volume

1063  
00:39:02,000 --> 00:39:04,033  
in orbit between Earth and Mars,

1064  
00:39:04,033 --> 00:39:05,400  
you know, like a taxi system

1065  
00:39:05,400 --> 00:39:08,033  
for going between  
the earth and Mars.

1066  
00:39:08,033 --> 00:39:11,733  
Now, the real objective  
with this waste is radiation.

1067  
00:39:11,733 --> 00:39:12,933  
Like I said before,

1068  
00:39:12,933 --> 00:39:15,266  
we have the technology  
to go to Mars.

1069  
00:39:15,266 --> 00:39:17,466  
The problem is,  
we can't afford to go to Mars.

1070  
00:39:17,466 --> 00:39:19,466  
And the real reason  
we can't afford to go to Mars

1071  
00:39:19,466 --> 00:39:21,566  
is radiation protection.

1072  
00:39:21,566 --> 00:39:23,766  
You're gonna get  
a good dose of radiation

1073  
00:39:23,766 --> 00:39:24,833  
on your way to Mars.

1074

00:39:24,833 --> 00:39:26,633

You're gonna get  
galactic radiation,

1075

00:39:26,633 --> 00:39:28,533

and you're gonna get  
solar radiation.

1076

00:39:28,533 --> 00:39:31,066

If a sun flare occurs  
on your way to Mars,

1077

00:39:31,066 --> 00:39:32,800

you could just get killed  
by the radiation.

1078

00:39:32,800 --> 00:39:34,266

Radiation levels  
could be high enough

1079

00:39:34,266 --> 00:39:35,933

that it would just  
kill you on the spot.

1080

00:39:35,933 --> 00:39:38,300

The galactic radiation  
is just gonna cause

1081

00:39:38,300 --> 00:39:40,233

a significant problem for you  
no matter what.

1082

00:39:40,233 --> 00:39:41,533

It's more of a constant.

1083

00:39:41,533 --> 00:39:46,033

This is a plot that shows  
galactic radiation

1084

00:39:46,033 --> 00:39:47,333  
and solar radiation,

1085  
00:39:47,333 --> 00:39:50,000  
not taking into account  
sun flares on solar radiation,

1086  
00:39:50,000 --> 00:39:53,000  
and the maximum dose limit  
that a human being can get

1087  
00:39:53,000 --> 00:39:54,733  
of radiation during  
the period of time.

1088  
00:39:54,733 --> 00:39:55,966  
And as you can see,

1089  
00:39:55,966 --> 00:40:00,900  
we can get right up  
to around, like, 170 days.

1090  
00:40:00,900 --> 00:40:02,700  
And after 170 days,

1091  
00:40:02,700 --> 00:40:04,633  
you are definitely  
giving yourself cancer

1092  
00:40:04,633 --> 00:40:05,800  
on this mission, right?

1093  
00:40:05,800 --> 00:40:07,133  
So that's a big problem.

1094  
00:40:07,133 --> 00:40:09,966  
So NASA has to provide  
radiation protection material.

1095

00:40:09,966 --> 00:40:12,366

This is assuming  
an aluminum canister

1096

00:40:12,366 --> 00:40:14,766

like an International  
Space Station canister.

1097

00:40:14,766 --> 00:40:17,000

So we need to provide  
radiation protection.

1098

00:40:17,000 --> 00:40:19,666

That means we need to bring  
material from the ground

1099

00:40:19,666 --> 00:40:21,833

in order to provide  
radiation protection.

1100

00:40:21,833 --> 00:40:22,833

If you look at that,

1101

00:40:22,833 --> 00:40:25,133

for a 240-day space mission,

1102

00:40:25,133 --> 00:40:29,466

you're talking about  
130,000 kilograms of water

1103

00:40:29,466 --> 00:40:32,500

that would be required  
to provide radiation protection.

1104

00:40:32,500 --> 00:40:34,233

Turns out, the only things  
that really work

1105

00:40:34,233 --> 00:40:36,700

for radiation protection

are water and polyethylene.

1106

00:40:36,700 --> 00:40:38,266

It's really the hydrogen  
is the key.

1107

00:40:38,266 --> 00:40:39,533

You need to get hydrogen.

1108

00:40:39,533 --> 00:40:42,133

Hydrogen is the key for  
providing radiation protection.

1109

00:40:42,133 --> 00:40:45,966

And 130,000 kilograms of water

1110

00:40:45,966 --> 00:40:47,933

means this mission  
is not going to happen.

1111

00:40:47,933 --> 00:40:49,333

There's no way we can afford

1112

00:40:49,333 --> 00:40:53,300

to launch those kinds  
of volumes into space.

1113

00:40:53,300 --> 00:40:55,133

If you just look  
at solar radiation,

1114

00:40:55,133 --> 00:40:56,300

it's not quite as bad.

1115

00:40:56,300 --> 00:41:00,266

You need about  
25,000 kilograms of water

1116

00:41:00,266 --> 00:41:01,533

in that application.

1117

00:41:01,533 --> 00:41:03,400

So where are we  
gonna get all this water?

1118

00:41:03,400 --> 00:41:06,300

Where are we gonna get all this  
radiation protection material?

1119

00:41:06,300 --> 00:41:08,233

Well, we have  
the International Space Station.

1120

00:41:08,233 --> 00:41:10,300

It has a water recycling system  
on it,

1121

00:41:10,300 --> 00:41:12,866

and it produces  
a concentrated byproduct.

1122

00:41:12,866 --> 00:41:15,333

They also produce feces on  
the International Space Station,

1123

00:41:15,333 --> 00:41:17,666

and they produce garbage on  
the International Space Station.

1124

00:41:17,666 --> 00:41:21,666

So the Water Wall's concept  
is to harvest all of that stuff,

1125

00:41:21,666 --> 00:41:24,466

that disgusting byproducts  
of human waste,

1126

00:41:24,466 --> 00:41:25,566

process it,

1127

00:41:25,566 --> 00:41:27,866  
and then use it  
for radiation protection

1128

00:41:27,866 --> 00:41:29,500  
in a mission, in a spacecraft

1129

00:41:29,500 --> 00:41:32,866  
that will be traveling  
between Earth and Mars.

1130

00:41:32,866 --> 00:41:34,266  
So how does that work?

1131

00:41:34,266 --> 00:41:36,933  
So if you look at the masses  
that are required for that,

1132

00:41:36,933 --> 00:41:38,533  
if you look at a six-person crew

1133

00:41:38,533 --> 00:41:40,000  
on the International  
Space Station

1134

00:41:40,000 --> 00:41:42,066  
achieving 80% water recovery,

1135

00:41:42,066 --> 00:41:44,966  
they're gonna produce  
about 6,500 kilograms a year,

1136

00:41:44,966 --> 00:41:46,600  
which means,  
for solar radiation,

1137

00:41:46,600 --> 00:41:48,133  
it would only take

about four years

1138

00:41:48,133 --> 00:41:50,033  
to stockpile enough material

1139

00:41:50,033 --> 00:41:52,366  
to provide that radiation  
protection material

1140

00:41:52,366 --> 00:41:55,800  
for a Bigelow type inflatable  
structure application.

1141

00:41:55,800 --> 00:41:57,533  
And if you want to do  
galactic radiation,

1142

00:41:57,533 --> 00:41:58,833  
it would take about ten years

1143

00:41:58,833 --> 00:42:00,533  
to produce  
that kind of waste water.

1144

00:42:00,533 --> 00:42:02,266  
You don't have to launch  
anything from the ground.

1145

00:42:02,266 --> 00:42:05,433  
You're basically getting all of  
this material in orbit for free.

1146

00:42:05,433 --> 00:42:06,600  
As a matter of fact,

1147

00:42:06,600 --> 00:42:08,700  
we typically destroy  
all that waste

1148

00:42:08,700 --> 00:42:11,100  
by reentry  
into Earth's atmosphere,

1149  
00:42:11,100 --> 00:42:13,800  
which costs money too,  
so you'll actually save money.

1150  
00:42:13,800 --> 00:42:15,233  
So the basic concept--

1151  
00:42:15,233 --> 00:42:18,200  
and there's a bunch of different  
life support functions

1152  
00:42:18,200 --> 00:42:19,800  
that all fall  
into the same concept.

1153  
00:42:19,800 --> 00:42:21,500  
And I have these  
pictorial graphics

1154  
00:42:21,500 --> 00:42:23,700  
to kind of describe  
how this works.

1155  
00:42:23,700 --> 00:42:25,566  
You have the crew  
in the spacecraft.

1156  
00:42:25,566 --> 00:42:26,833  
All of their waste water

1157  
00:42:26,833 --> 00:42:29,433  
is put into  
these small little bags.

1158  
00:42:29,433 --> 00:42:31,200  
The bags then process

the waste water

1159

00:42:31,200 --> 00:42:34,066

using forward osmosis  
to remove the water out of them.

1160

00:42:34,066 --> 00:42:36,466

And the water then goes  
through an RO system,

1161

00:42:36,466 --> 00:42:38,266

and it's provided  
back to the crew.

1162

00:42:38,266 --> 00:42:40,833

The bags eventually become  
completely filled

1163

00:42:40,833 --> 00:42:43,933

with this basically gross,  
solid material.

1164

00:42:43,933 --> 00:42:45,466

It's still mostly water,

1165

00:42:45,466 --> 00:42:47,866

but it has a lot of solids,  
byproducts into it.

1166

00:42:47,866 --> 00:42:52,100

And then those  
are vacuum-processed,

1167

00:42:52,100 --> 00:42:55,300

and then the solid bags  
become like tiles.

1168

00:42:55,300 --> 00:42:57,100

They become  
radiation protection tiles.

1169

00:42:57,100 --> 00:42:58,433

And then these tiles are placed

1170

00:42:58,433 --> 00:43:00,166

on the outside wall

of the spacecraft.

1171

00:43:00,166 --> 00:43:01,466

And so, as a function of time,

1172

00:43:01,466 --> 00:43:03,933

the spacecraft capacity

for radiation protection

1173

00:43:03,933 --> 00:43:08,366

increases as the humans generate

more and more waste.

1174

00:43:08,366 --> 00:43:09,633

The basic bag we use

1175

00:43:09,633 --> 00:43:11,100

is a commercially

available product.

1176

00:43:11,100 --> 00:43:13,100

It's a Hydration Technology

XPack bag.

1177

00:43:13,100 --> 00:43:14,733

It's a forward osmosis bag.

1178

00:43:14,733 --> 00:43:15,833

This is a great little product,

1179

00:43:15,833 --> 00:43:17,700

particularly if you live

here in California

1180

00:43:17,700 --> 00:43:18,866  
where there's earthquakes.

1181

00:43:18,866 --> 00:43:20,366  
For earthquakes, they tell you  
you should keep

1182

00:43:20,366 --> 00:43:21,966  
five gallons of water  
underneath your bed,

1183

00:43:21,966 --> 00:43:24,633  
and ever year you should replace  
the five gallons of water.

1184

00:43:24,633 --> 00:43:26,100  
How many people do that?

1185

00:43:26,100 --> 00:43:27,966  
Nobody does that, right?

1186

00:43:27,966 --> 00:43:29,866  
Well, with this little bag,  
you can buy this little bag,

1187

00:43:29,866 --> 00:43:31,000  
it has about a ten-year life,

1188

00:43:31,000 --> 00:43:33,133  
you just throw that  
under your bed,

1189

00:43:33,133 --> 00:43:34,500  
and when there's an earthquake  
and you need water,

1190

00:43:34,500 --> 00:43:35,866  
wake up, pee in the bag,

1191

00:43:35,866 --> 00:43:37,400

and you got  
all the water you want.

1192

00:43:37,400 --> 00:43:38,900

As a matter of fact,  
we actually sometimes

1193

00:43:38,900 --> 00:43:41,466

have cocktail hours  
where we make all the interns

1194

00:43:41,466 --> 00:43:43,500

pee in a bag, and then we have  
a cocktail hour

1195

00:43:43,500 --> 00:43:45,266

and make them all  
drink their own urine.

1196

00:43:45,266 --> 00:43:48,100

They get really  
excited about that.

1197

00:43:48,100 --> 00:43:50,300

This is an example  
of an actual test

1198

00:43:50,300 --> 00:43:51,500

producing this material.

1199

00:43:51,500 --> 00:43:54,366

So this is urine  
brine concentrate,

1200

00:43:54,366 --> 00:43:57,566

feces, and garbage  
all mixed together.

1201

00:43:57,566 --> 00:43:59,000

And then we process it  
in the bag,

1202

00:43:59,000 --> 00:44:01,766

and you kind of see we produce  
this kind of tarry material.

1203

00:44:01,766 --> 00:44:03,900

It's kind of like toffee,  
basically, is what it is.

1204

00:44:03,900 --> 00:44:05,366

And we took those samples  
and sent them

1205

00:44:05,366 --> 00:44:07,466

and had radiation dosing  
done with them.

1206

00:44:07,466 --> 00:44:10,033

What we found was  
that we actually can dry them

1207

00:44:10,033 --> 00:44:12,800

a little too much, and we  
need to dry them a little less.

1208

00:44:12,800 --> 00:44:14,266

They need to have  
a little higher water content.

1209

00:44:14,266 --> 00:44:15,866

Our real focus was,  
dry them enough

1210

00:44:15,866 --> 00:44:17,333

so that bacteria  
can't grow in them,

1211  
00:44:17,333 --> 00:44:18,500  
so they're basically sterile,

1212  
00:44:18,500 --> 00:44:20,166  
so nothing can grow  
inside of them.

1213  
00:44:20,166 --> 00:44:21,266  
But that actually resulted

1214  
00:44:21,266 --> 00:44:23,066  
in a little bit too low  
water content,

1215  
00:44:23,066 --> 00:44:25,933  
so we have some more processing  
to do there.

1216  
00:44:25,933 --> 00:44:27,066  
But that's the basic idea.

1217  
00:44:27,066 --> 00:44:28,500  
So you're gonna take these bags.

1218  
00:44:28,500 --> 00:44:30,666  
All those endpoints  
of the life support system

1219  
00:44:30,666 --> 00:44:32,766  
are gonna be processed  
inside the bags.

1220  
00:44:32,766 --> 00:44:33,966  
You won't cut them open.

1221  
00:44:33,966 --> 00:44:35,266  
And then the bags are assembled,

1222

00:44:35,266 --> 00:44:37,733

either on the outside  
or the inside of the spacecraft,

1223

00:44:37,733 --> 00:44:40,766

to provide radiation protection  
as a function of time.

1224

00:44:40,766 --> 00:44:43,933

So the system has  
a life expectancy.

1225

00:44:43,933 --> 00:44:46,700

We also do this  
for humidity control.

1226

00:44:46,700 --> 00:44:48,333

Same thing, we have a bag.

1227

00:44:48,333 --> 00:44:50,700

The bag has a different  
type of membrane

1228

00:44:50,700 --> 00:44:52,933

that allows gases  
to pass through it.

1229

00:44:52,933 --> 00:44:54,833

So the humidity,  
the water vapor in the air,

1230

00:44:54,833 --> 00:44:56,100

goes inside the bag.

1231

00:44:56,100 --> 00:44:58,266

The water's cooled  
through a cooling system,

1232

00:44:58,266 --> 00:44:59,900

and then it accumulates

the water in the bag.

1233

00:44:59,900 --> 00:45:01,633

We recycle the water in the bag

1234

00:45:01,633 --> 00:45:04,166

and provide fresh water

back to the crew.

1235

00:45:04,166 --> 00:45:07,766

Carbon dioxide control

and oxygen generation is done

1236

00:45:07,766 --> 00:45:09,766

by growing algae

inside these bags.

1237

00:45:09,766 --> 00:45:11,266

We populate it with algae.

1238

00:45:11,266 --> 00:45:13,933

Again, it's a membrane that

allows gas to pass through it.

1239

00:45:13,933 --> 00:45:15,966

The carbon dioxide

goes into the bag.

1240

00:45:15,966 --> 00:45:19,933

The algae use the carbon dioxide

as a food source.

1241

00:45:19,933 --> 00:45:22,066

They also electrolyze water

and produce oxygen,

1242

00:45:22,066 --> 00:45:23,233

so oxygen comes out of it.

1243

00:45:23,233 --> 00:45:24,400

And then, eventually,

1244

00:45:24,400 --> 00:45:26,566

the bag becomes completely full  
of dead algae,

1245

00:45:26,566 --> 00:45:28,333

and then it's processed  
similar to the waste water

1246

00:45:28,333 --> 00:45:29,566

and turned into a tile

1247

00:45:29,566 --> 00:45:32,733

used for radiation protection  
as well.

1248

00:45:32,733 --> 00:45:35,600

Now, these systems are put  
on the outside.

1249

00:45:35,600 --> 00:45:39,000

So these are the bags here  
on the outside of the habitat,

1250

00:45:39,000 --> 00:45:40,200

the Bigelow habitat.

1251

00:45:40,200 --> 00:45:41,866

And that's kind of  
a cross section showing.

1252

00:45:41,866 --> 00:45:43,466

It takes multiple layers  
of the bag.

1253

00:45:43,466 --> 00:45:46,000

One bag is not gonna provide  
enough radiation protection.

1254

00:45:46,000 --> 00:45:48,266

So you have to provide  
multiple layers of the bags

1255

00:45:48,266 --> 00:45:53,166

in order to get the targeted  
level of radiation protection.

1256

00:45:53,166 --> 00:45:54,700

This is a diagram  
that just kind of goes

1257

00:45:54,700 --> 00:45:57,066

into a little bit more detail  
on how these bags will be placed

1258

00:45:57,066 --> 00:45:59,133

and how they will be plumbed  
together on the inside.

1259

00:45:59,133 --> 00:46:00,333

There's a protective screen

1260

00:46:00,333 --> 00:46:02,133

so that you don't  
put a hole in them

1261

00:46:02,133 --> 00:46:05,833

if something gets free  
out of the system.

1262

00:46:05,833 --> 00:46:07,400

So this is an analysis  
that we did

1263

00:46:07,400 --> 00:46:08,933

looking at  
the radiation protection.

1264

00:46:08,933 --> 00:46:10,400

So these are layers of bags.

1265

00:46:10,400 --> 00:46:12,133

How many layers of bags  
would you need

1266

00:46:12,133 --> 00:46:13,866

in order to get  
this protection level?

1267

00:46:13,866 --> 00:46:16,066

So this is for  
the solar radiation,

1268

00:46:16,066 --> 00:46:18,133

and this is for  
the galactic radiation.

1269

00:46:18,133 --> 00:46:21,200

And, really, within about  
two layers of bags,

1270

00:46:21,200 --> 00:46:23,133

we can pretty much sequester

1271

00:46:23,133 --> 00:46:25,633

all of the solar radiation  
very simply.

1272

00:46:25,633 --> 00:46:26,800

The galactic radiation

1273

00:46:26,800 --> 00:46:28,466

is a much more difficult one  
to deal with.

1274

00:46:28,466 --> 00:46:31,066

It takes actually

quite a few layers of bags

1275

00:46:31,066 --> 00:46:33,066

in order to get  
to an acceptable level

1276

00:46:33,066 --> 00:46:34,866

of radiation exposure.

1277

00:46:34,866 --> 00:46:36,200

Now, what you have to do is,

1278

00:46:36,200 --> 00:46:37,500

you have to tailor  
the number of bags,

1279

00:46:37,500 --> 00:46:38,766

the number  
of radiation protection

1280

00:46:38,766 --> 00:46:40,066

for the duration of the mission,

1281

00:46:40,066 --> 00:46:42,600

because, of course, radiation  
is an exposure function,

1282

00:46:42,600 --> 00:46:45,066

and so it's a function  
of how often it is exposed.

1283

00:46:45,066 --> 00:46:46,900

The other thing you get  
for this technology is,

1284

00:46:46,900 --> 00:46:48,800

you get all  
of your life support functions

1285

00:46:48,800 --> 00:46:49,900  
integrated into it.

1286  
00:46:49,900 --> 00:46:51,466  
And this is a very  
complicated diagram.

1287  
00:46:51,466 --> 00:46:53,000  
I'm not gonna go through it  
in a lot of detail.

1288  
00:46:53,000 --> 00:46:54,700  
But very similar  
to that one I showed

1289  
00:46:54,700 --> 00:46:56,600  
for the International  
Space Station system

1290  
00:46:56,600 --> 00:46:57,900  
earlier in the presentation,

1291  
00:46:57,900 --> 00:47:00,500  
where the crew is the center.

1292  
00:47:00,500 --> 00:47:02,266  
We have an air  
revitalization system

1293  
00:47:02,266 --> 00:47:05,233  
that has the algae in it  
and humidity control.

1294  
00:47:05,233 --> 00:47:06,333  
We also have bags

1295  
00:47:06,333 --> 00:47:08,866  
used for volatile  
contaminant destruction,

1296  
00:47:08,866 --> 00:47:10,233  
climate control,

1297  
00:47:10,233 --> 00:47:12,866  
and then the urine  
and black water processing,

1298  
00:47:12,866 --> 00:47:14,466  
and there are also  
some power systems

1299  
00:47:14,466 --> 00:47:18,200  
that we can integrate into that,  
as well, for doing it.

1300  
00:47:18,200 --> 00:47:19,533  
How much time do I have left?

1301  
00:47:19,533 --> 00:47:21,000  
Five, perfect.

1302  
00:47:21,000 --> 00:47:24,233  
So, what I've outlined here  
are these basic concepts

1303  
00:47:24,233 --> 00:47:26,300  
of taking these  
biological functions,

1304  
00:47:26,300 --> 00:47:30,100  
not actually biology,  
but the biological functions,

1305  
00:47:30,100 --> 00:47:32,500  
and integrating them  
into mechanical systems

1306  
00:47:32,500 --> 00:47:35,000  
to produce a new class

of technologies

1307

00:47:35,000 --> 00:47:38,166

that are integrated, we call,  
biologic organs,

1308

00:47:38,166 --> 00:47:39,933

or biologic functions.

1309

00:47:39,933 --> 00:47:42,566

We haven't only been doing those  
for space flight applications.

1310

00:47:42,566 --> 00:47:43,566

We've also been doing

1311

00:47:43,566 --> 00:47:45,533

terrestrial applications  
for that.

1312

00:47:45,533 --> 00:47:47,333

And this is a picture  
of the Green Building.

1313

00:47:47,333 --> 00:47:49,633

It's right across the street  
from us, right over here.

1314

00:47:49,633 --> 00:47:51,500

And that system has  
a water recycling system.

1315

00:47:51,500 --> 00:47:53,666

It has a forward osmosis  
water recycling system

1316

00:47:53,666 --> 00:47:54,733

integrated into it,

1317

00:47:54,733 --> 00:47:56,333

so it functions

the same basic way

1318

00:47:56,333 --> 00:47:58,200

your small intestine functions.

1319

00:47:58,200 --> 00:48:00,766

Takes all the hygiene water,  
purifies it,

1320

00:48:00,766 --> 00:48:02,866

and we use it for flushing  
toilets in the building.

1321

00:48:02,866 --> 00:48:04,366

And that's a picture  
of the system.

1322

00:48:04,366 --> 00:48:07,200

It's been operating now  
for about two years,

1323

00:48:07,200 --> 00:48:08,466

pretty much continuously.

1324

00:48:08,466 --> 00:48:10,133

We actually haven't  
been putting water

1325

00:48:10,133 --> 00:48:11,466

back in the building yet.

1326

00:48:11,466 --> 00:48:13,633

That's something  
that's gonna happen pretty soon.

1327

00:48:13,633 --> 00:48:15,266

NASA, we're really interested  
in testing it

1328

00:48:15,266 --> 00:48:16,633  
and getting operational data  
out of it.

1329

00:48:16,633 --> 00:48:18,133  
That's the primary objective.

1330

00:48:18,133 --> 00:48:20,933  
It's a way for us  
to test forward osmosis systems

1331

00:48:20,933 --> 00:48:24,100  
for space flight applications  
for years and years and years

1332

00:48:24,100 --> 00:48:26,366  
with human waste as the input  
into them.

1333

00:48:26,366 --> 00:48:28,266  
The other thing that came  
out of that process,

1334

00:48:28,266 --> 00:48:30,500  
so the Army heard about  
the Green Building application,

1335

00:48:30,500 --> 00:48:31,600  
and they asked us to build

1336

00:48:31,600 --> 00:48:35,066  
one of these  
biologic systems for them.

1337

00:48:35,066 --> 00:48:36,866  
So we built  
a forward operating base

1338

00:48:36,866 --> 00:48:38,600  
water recycling system.

1339  
00:48:38,600 --> 00:48:41,300  
It uses the synthetic  
biological membrane

1340  
00:48:41,300 --> 00:48:42,633  
inside of it.

1341  
00:48:42,633 --> 00:48:44,200  
And this is for  
forward operating base.

1342  
00:48:44,200 --> 00:48:46,300  
Forward operating base  
is sort of the smallest

1343  
00:48:46,300 --> 00:48:49,366  
fixed facility that the Army  
operates out in the field.

1344  
00:48:49,366 --> 00:48:52,166  
And if you look at conflicts  
like Iraq and Afghanistan,

1345  
00:48:52,166 --> 00:48:54,433  
the highest death rate  
associated with those

1346  
00:48:54,433 --> 00:48:55,700  
was contract employees,

1347  
00:48:55,700 --> 00:48:58,066  
so local Afghani,  
Iraqi employees

1348  
00:48:58,066 --> 00:48:59,866  
working for the U.S. Army,

1349

00:48:59,866 --> 00:49:02,266

trucking material

to forward operating bases,

1350

00:49:02,266 --> 00:49:05,666

trucking water, fuel

to forward operating bases,

1351

00:49:05,666 --> 00:49:08,400

and then waste back out

from forward operating bases.

1352

00:49:08,400 --> 00:49:10,500

So the Army wants to develop

a forward operating base

1353

00:49:10,500 --> 00:49:11,966

that's completely

self-sufficient,

1354

00:49:11,966 --> 00:49:14,166

similar to like a Mars base

kind of an application.

1355

00:49:14,166 --> 00:49:16,033

And so this technology

was developed for that.

1356

00:49:16,033 --> 00:49:17,333

It's been very successful.

1357

00:49:17,333 --> 00:49:19,400

It's gone through

a very competitive process.

1358

00:49:19,400 --> 00:49:21,866

And it does look like it is

gonna become the baseline system

1359

00:49:21,866 --> 00:49:24,766  
for the U.S. Army in the future.

1360  
00:49:24,766 --> 00:49:27,766  
Okay, so, the conclusions here.

1361  
00:49:27,766 --> 00:49:30,300  
So the objective  
of this presentation

1362  
00:49:30,300 --> 00:49:32,833  
was to give all  
of you guys ideas

1363  
00:49:32,833 --> 00:49:34,033  
so that when you go on,

1364  
00:49:34,033 --> 00:49:36,166  
do Master's, Ph.D. theses,

1365  
00:49:36,166 --> 00:49:38,166  
you know what  
you're supposed to be doing.

1366  
00:49:38,166 --> 00:49:39,866  
You write a proposal,  
you submit it to NASA,

1367  
00:49:39,866 --> 00:49:42,366  
I review your proposal,  
and you get funding, right?

1368  
00:49:42,366 --> 00:49:43,566  
It's a pretty simple equation.

1369  
00:49:43,566 --> 00:49:45,033  
And what we're really  
interested in

1370

00:49:45,033 --> 00:49:46,266  
is reliability issues.

1371  
00:49:46,266 --> 00:49:48,266  
Any kind of issues  
that address reliability,

1372  
00:49:48,266 --> 00:49:51,833  
that's a key aspect  
in the life support arena.

1373  
00:49:51,833 --> 00:49:53,666  
The area that we're doing  
primarily work in

1374  
00:49:53,666 --> 00:49:54,866  
is looking at integrating

1375  
00:49:54,866 --> 00:49:57,066  
biological and mechanical  
systems together.

1376  
00:49:57,066 --> 00:49:58,933  
Not developing  
biological systems.

1377  
00:49:58,933 --> 00:50:00,233  
We have done that before.

1378  
00:50:00,233 --> 00:50:02,700  
We've done bioreactors  
to treat waste water.

1379  
00:50:02,700 --> 00:50:05,166  
Bioreactors produce  
carbon dioxide.

1380  
00:50:05,166 --> 00:50:06,733  
Things that produce  
carbon dioxide,

1381

00:50:06,733 --> 00:50:08,433

we call them crew members.

1382

00:50:08,433 --> 00:50:09,933

We don't need

any more crew members.

1383

00:50:09,933 --> 00:50:12,366

We don't want any more carbon  
dioxide in the atmosphere.

1384

00:50:12,366 --> 00:50:14,300

But integrating  
biological systems

1385

00:50:14,300 --> 00:50:17,100

into making, for instance,  
biological materials

1386

00:50:17,100 --> 00:50:19,600

that have unique characteristics  
associated with them

1387

00:50:19,600 --> 00:50:20,966

that provide reliability,

1388

00:50:20,966 --> 00:50:24,133

those are the types of things  
that we're looking for.

1389

00:50:24,133 --> 00:50:25,533

So some examples  
of other projects

1390

00:50:25,533 --> 00:50:26,800

that we've been looking at is,

1391

00:50:26,800 --> 00:50:28,266

there's a group,  
a university group,

1392  
00:50:28,266 --> 00:50:30,933  
that's actually making  
CCD cameras out of biological.

1393  
00:50:30,933 --> 00:50:32,066  
So they grow bacteria.

1394  
00:50:32,066 --> 00:50:33,666  
They genetically engineer  
the bacteria

1395  
00:50:33,666 --> 00:50:35,066  
to express a protein.

1396  
00:50:35,066 --> 00:50:37,800  
When light hits the bacteria,  
that protein is expressed,

1397  
00:50:37,800 --> 00:50:39,166  
the protein is conductive,

1398  
00:50:39,166 --> 00:50:40,466  
and you can measure the change

1399  
00:50:40,466 --> 00:50:41,966  
in the amount  
of proteins into it,

1400  
00:50:41,966 --> 00:50:43,666  
and you can actually make  
a small camera

1401  
00:50:43,666 --> 00:50:45,133  
that works using that technique.

1402  
00:50:45,133 --> 00:50:47,533

And CCD cameras are very susceptible to radiation,

1403

00:50:47,533 --> 00:50:48,766  
so they're a problem.

1404

00:50:48,766 --> 00:50:49,900  
Heart--think of your heart.

1405

00:50:49,900 --> 00:50:51,533  
Your heart is a pump,

1406

00:50:51,533 --> 00:50:53,500  
runs 24 hours a day,  
7 days a week,

1407

00:50:53,500 --> 00:50:56,600  
365 days a year for 80 years.

1408

00:50:56,600 --> 00:51:00,333  
I mean, there are  
no pumps commercially or NASA

1409

00:51:00,333 --> 00:51:02,600  
that come anywhere near  
that level of reliability.

1410

00:51:02,600 --> 00:51:06,766  
That is the most reliable pump,  
by far, out there.

1411

00:51:06,766 --> 00:51:08,433  
We also have a project  
where we're looking

1412

00:51:08,433 --> 00:51:10,366  
at developing  
an autoimmune system,

1413

00:51:10,366 --> 00:51:11,866  
a synthetic immune system.

1414  
00:51:11,866 --> 00:51:14,033  
So the idea is,  
you're on your way to Mars,

1415  
00:51:14,033 --> 00:51:16,500  
and you get diagnosed  
with some sort of a disease

1416  
00:51:16,500 --> 00:51:17,833  
or some sort of sickness.

1417  
00:51:17,833 --> 00:51:20,100  
And this system allows you to,  
like your body would,

1418  
00:51:20,100 --> 00:51:21,533  
to produce antibiotics,

1419  
00:51:21,533 --> 00:51:23,500  
to produce proteins,  
produce enzymes,

1420  
00:51:23,500 --> 00:51:26,600  
to respond to the disease  
that you have there.

1421  
00:51:26,600 --> 00:51:28,166  
And that's, again,  
done by genetically

1422  
00:51:28,166 --> 00:51:30,933  
engineering E. coli  
to express those compounds.

1423  
00:51:30,933 --> 00:51:32,800  
All right, so that's all  
the time I have for it.

1424

00:51:32,800 --> 00:51:35,000

So if anybody has  
any questions...

1425

00:51:35,000 --> 00:51:36,200

Thank you.

1426

00:51:36,200 --> 00:51:39,200

[applause]

1427

00:51:43,166 --> 00:51:45,233

- So we have time  
for a couple of questions.

1428

00:51:45,233 --> 00:51:46,400

So if you have a question,

1429

00:51:46,400 --> 00:51:48,066

raise your hand,  
wait for the microphone,

1430

00:51:48,066 --> 00:51:49,866

and please ask  
one question only.

1431

00:51:49,866 --> 00:51:51,866

Thank you.

1432

00:52:00,066 --> 00:52:02,066

- Great talk, Michael.

1433

00:52:02,066 --> 00:52:03,533

I have a specific question  
for you,

1434

00:52:03,533 --> 00:52:05,600

and then something general  
to follow up.

1435

00:52:05,600 --> 00:52:07,766

The specific question  
is that biological systems

1436

00:52:07,766 --> 00:52:09,433

are wonderful, no doubt,

1437

00:52:09,433 --> 00:52:13,833

but it's kind of a misconception  
to say that they're so stable,

1438

00:52:13,833 --> 00:52:16,266

because they're repairing  
themselves all the time,

1439

00:52:16,266 --> 00:52:18,633

and the repair takes energy,

1440

00:52:18,633 --> 00:52:19,966

so that the system,

1441

00:52:19,966 --> 00:52:21,966

although it's  
wonderfully efficient

1442

00:52:21,966 --> 00:52:24,200

in terms of how long it lasts,

1443

00:52:24,200 --> 00:52:27,533

it's actually repaired a lot.

1444

00:52:27,533 --> 00:52:30,300

So you kind of described that  
with the lipids.

1445

00:52:30,300 --> 00:52:32,000

- Yeah, so let me  
give you an example of that.

1446

00:52:32,000 --> 00:52:33,500

So, in the biomembrane project,

1447

00:52:33,500 --> 00:52:36,633

where we were repairing  
the membrane as it gets damaged,

1448

00:52:36,633 --> 00:52:39,666

we need a source of energy,  
right, to do that.

1449

00:52:39,666 --> 00:52:41,933

And there's two sources  
of energy that we're looking at.

1450

00:52:41,933 --> 00:52:43,066

One of them is the feed.

1451

00:52:43,066 --> 00:52:44,766

The feed is human waste.

1452

00:52:44,766 --> 00:52:47,433

So that has nitrogen,  
phosphorous, sulfur in it.

1453

00:52:47,433 --> 00:52:48,966

It has an organic content.

1454

00:52:48,966 --> 00:52:51,233

And so the idea is, the bacteria  
would actually live

1455

00:52:51,233 --> 00:52:53,700

off of that organic content  
that's there.

1456

00:52:53,700 --> 00:52:55,600

Somewhat problematic,

because it is waste,

1457

00:52:55,600 --> 00:52:57,466

so a lot of the energy  
has been removed out of it.

1458

00:52:57,466 --> 00:52:59,533

It's not a high-energy  
solution.

1459

00:52:59,533 --> 00:53:01,066

So another approach  
we're looking at

1460

00:53:01,066 --> 00:53:02,733

is using actually cyanobacteria,

1461

00:53:02,733 --> 00:53:04,833

genetically engineering  
cyanobacteria

1462

00:53:04,833 --> 00:53:07,366

to express the fatty acids  
that we're interesting in.

1463

00:53:07,366 --> 00:53:09,133

And then we could use  
carbon dioxide

1464

00:53:09,133 --> 00:53:11,433

and crew cabin light  
as a source of energy.

1465

00:53:11,433 --> 00:53:12,833

But you're absolutely correct.

1466

00:53:12,833 --> 00:53:15,666

You know, biological systems  
do carry some overhead--

1467

00:53:15,666 --> 00:53:17,500

I think that's what  
you're kind of driving at--

1468

00:53:17,500 --> 00:53:19,933

associated with their operating.

1469

00:53:19,933 --> 00:53:21,333

But, you know, in many cases,

1470

00:53:21,333 --> 00:53:23,100

like with regard  
to a separation membrane

1471

00:53:23,100 --> 00:53:24,600

as treating human waste,

1472

00:53:24,600 --> 00:53:27,533

I mean, bacteria's gonna grow  
in there one way or another,

1473

00:53:27,533 --> 00:53:30,333

so you might as well have it  
do something good for you.

1474

00:53:30,333 --> 00:53:31,866

Right?

1475

00:53:41,033 --> 00:53:44,433

- So water scarcity is  
definitely an issue in space.

1476

00:53:44,433 --> 00:53:47,400

But as you highlighted  
with the Army topic,

1477

00:53:47,400 --> 00:53:49,333

that it's also an issue  
on Earth.

1478

00:53:49,333 --> 00:53:50,666

There are a lot  
of people who don't

1479

00:53:50,666 --> 00:53:51,866

have access to clean water.

1480

00:53:51,866 --> 00:53:54,266

Are there any lessons  
from your studies so far

1481

00:53:54,266 --> 00:53:57,366

in forward osmosis membranes  
that could be applied

1482

00:53:57,366 --> 00:54:00,066

to water technologies  
here on Earth?

1483

00:54:00,066 --> 00:54:01,433

- Yeah, so this is an area

1484

00:54:01,433 --> 00:54:03,066

that we do, actually,  
a lot of work in.

1485

00:54:03,066 --> 00:54:06,266

And I only kind of touched  
on that with the Army system.

1486

00:54:06,266 --> 00:54:09,866

So here in California,  
you have a drought, right?

1487

00:54:09,866 --> 00:54:11,900

And the governor comes out  
and says, you know,

1488

00:54:11,900 --> 00:54:15,666

you got to cut your water  
consumption by 20%, right?

1489

00:54:15,666 --> 00:54:17,766

Why can't I just pull out  
my credit card

1490

00:54:17,766 --> 00:54:19,100

and solve that problem?

1491

00:54:19,100 --> 00:54:20,566

Why can't I go  
down to Home Depot

1492

00:54:20,566 --> 00:54:21,766

with my credit card

1493

00:54:21,766 --> 00:54:23,433

and just eliminat the drought  
as a problem,

1494

00:54:23,433 --> 00:54:25,166

go down there,  
buy a water recycling system,

1495

00:54:25,166 --> 00:54:26,400

hook it up in my house, right?

1496

00:54:26,400 --> 00:54:28,233

Well, the reason is,  
because you go down there,

1497

00:54:28,233 --> 00:54:29,566

you buy that,  
put it in your house,

1498

00:54:29,566 --> 00:54:31,133

you're never gonna maintain it,  
right?

1499

00:54:31,133 --> 00:54:32,466

You're never gonna test it.

1500

00:54:32,466 --> 00:54:34,900

You're never gonna make sure  
the water is good

1501

00:54:34,900 --> 00:54:36,200

that's coming out of it.

1502

00:54:36,200 --> 00:54:37,966

You're just gonna go there,  
plug it in,

1503

00:54:37,966 --> 00:54:40,800

and that thing better work  
without any maintenance

1504

00:54:40,800 --> 00:54:43,233

for a pre-determined  
life period of time,

1505

00:54:43,233 --> 00:54:45,166

and it better be cheap  
to operate, right?

1506

00:54:45,166 --> 00:54:46,733

It's almost identical

1507

00:54:46,733 --> 00:54:48,633

to the criteria  
for a Mars mission.

1508

00:54:48,633 --> 00:54:51,000

That system needs  
to run continuously

1509

00:54:51,000 --> 00:54:52,466

for a three-year  
period of time

1510  
00:54:52,466 --> 00:54:53,500  
without no maintenance

1511  
00:54:53,500 --> 00:54:55,033  
and not require any testing,

1512  
00:54:55,033 --> 00:54:56,333  
because you're  
on your way to Mars.

1513  
00:54:56,333 --> 00:54:58,166  
If the tests say  
that you can't drink the water,

1514  
00:54:58,166 --> 00:54:59,366  
that's not particularly useful,

1515  
00:54:59,366 --> 00:55:01,166  
because you're drinking  
the water anyway, right?

1516  
00:55:01,166 --> 00:55:03,700  
You don't have any option,  
any backup situation.

1517  
00:55:03,700 --> 00:55:08,666  
So, to take that--put the power  
in the consumer's hands

1518  
00:55:08,666 --> 00:55:10,300  
to address  
the water recycling issue,

1519  
00:55:10,300 --> 00:55:12,000  
you need to have  
water recycling systems

1520

00:55:12,000 --> 00:55:15,000

that are very, very reliable,  
that don't fail.

1521

00:55:15,000 --> 00:55:17,366

And so the biomembrane project  
is a project

1522

00:55:17,366 --> 00:55:19,466

that we feel is a real  
game-changer in that area,

1523

00:55:19,466 --> 00:55:20,766

because that allows you, then,

1524

00:55:20,766 --> 00:55:23,133

to develop a water recycling  
system, for instance,

1525

00:55:23,133 --> 00:55:24,633

that you might hook up  
to your washing machine,

1526

00:55:24,633 --> 00:55:26,600

that would recycle the water  
in your washing machine.

1527

00:55:26,600 --> 00:55:29,800

And it has self-repair  
characteristics to it, right?

1528

00:55:29,800 --> 00:55:31,200

So, fine, don't maintain it.

1529

00:55:31,200 --> 00:55:32,766

Don't pay any attention to it.

1530

00:55:32,766 --> 00:55:34,500

That thing will just

sit over there

1531

00:55:34,500 --> 00:55:35,500

and repair itself on its own.

1532

00:55:35,500 --> 00:55:36,900

So you're absolutely correct.

1533

00:55:36,900 --> 00:55:39,433

And we have some big proposals  
in the state of California

1534

00:55:39,433 --> 00:55:42,333

to do human health studies  
and human factor studies,

1535

00:55:42,333 --> 00:55:43,933

and do 300, 400 homes,

1536

00:55:43,933 --> 00:55:46,133

put water recycling systems  
into them,

1537

00:55:46,133 --> 00:55:47,766

that are going right now  
through the state.

1538

00:55:47,766 --> 00:55:49,000

And whether they get  
funded or not

1539

00:55:49,000 --> 00:55:50,800

depends on the state, I guess.

1540

00:55:50,800 --> 00:55:51,833

Yeah.

1541

00:55:51,833 --> 00:55:54,000

- So, with that,

please join me

1542

00:55:54,000 --> 00:55:56,300

in thanking Michael Flynn  
for an excellent talk.