Modeling Pipeline Delivery of Compressed Gaseous Hydrogen to Urban Refueling Stations

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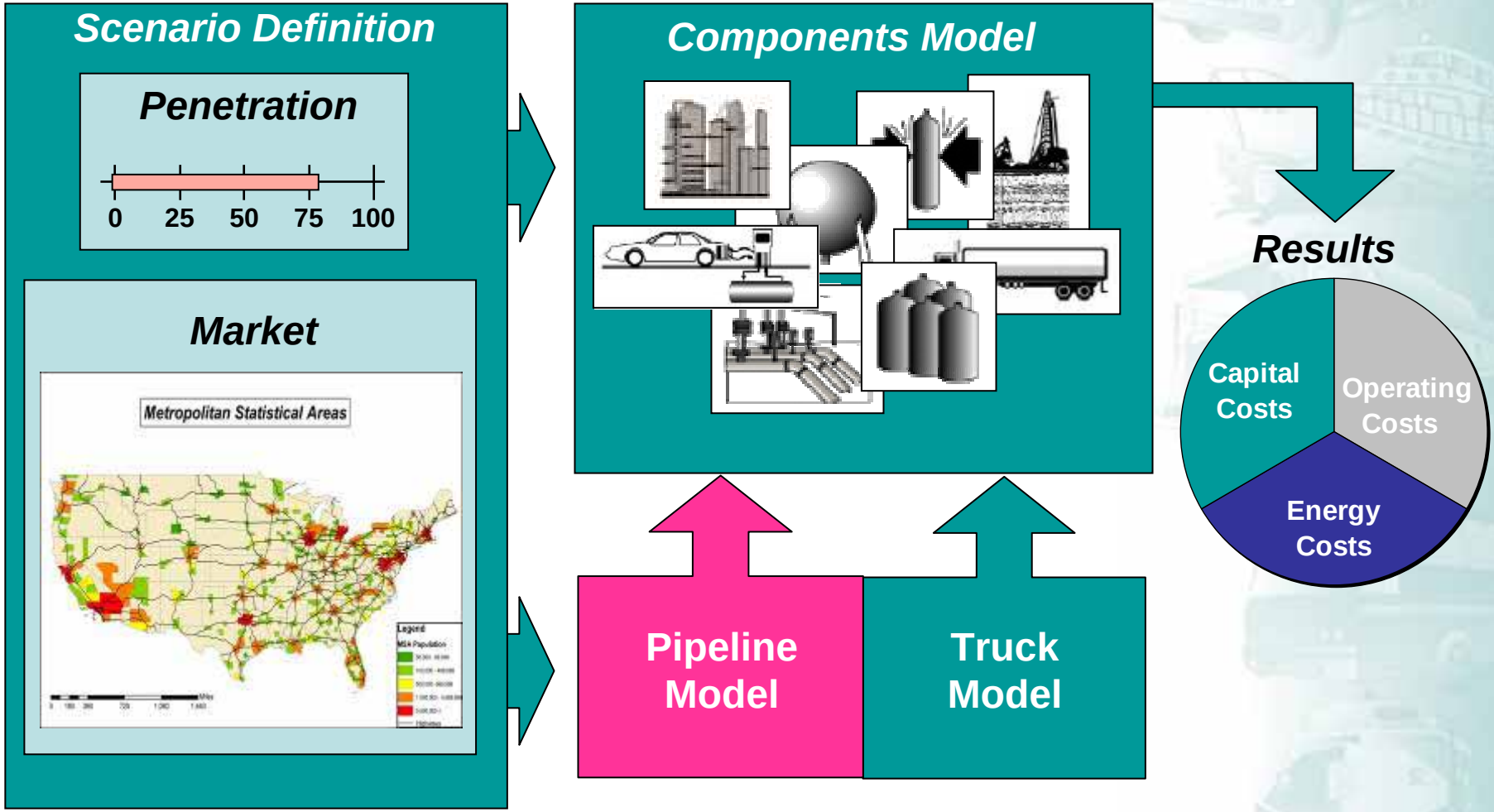
Topics

- **Delivery modeling process**
- **Pipeline model**
  - Approach
  - Key assumptions
- **Results**
- **Next Steps**

H2A Hydrogen Delivery Model Includes:

- **Production Site**
  - Compression
  - Gaseous storage
- **Liquid Distribution**
  - Liquefaction
  - LH_2 terminals
  - LH_2 storage
  - LH_2 trucks
- **Gaseous Distribution**
  - Compression
  - Geologic storage
  - ***Pipelines***
  - Compressed gas terminals
  - Compressed gas trucks
- **Forecourt (Refueling Station)**
  - Storage
  - Compression (if applicable)

Pipeline Model Translates Scenario Demand to Component Sizing for H2A Cost Estimation

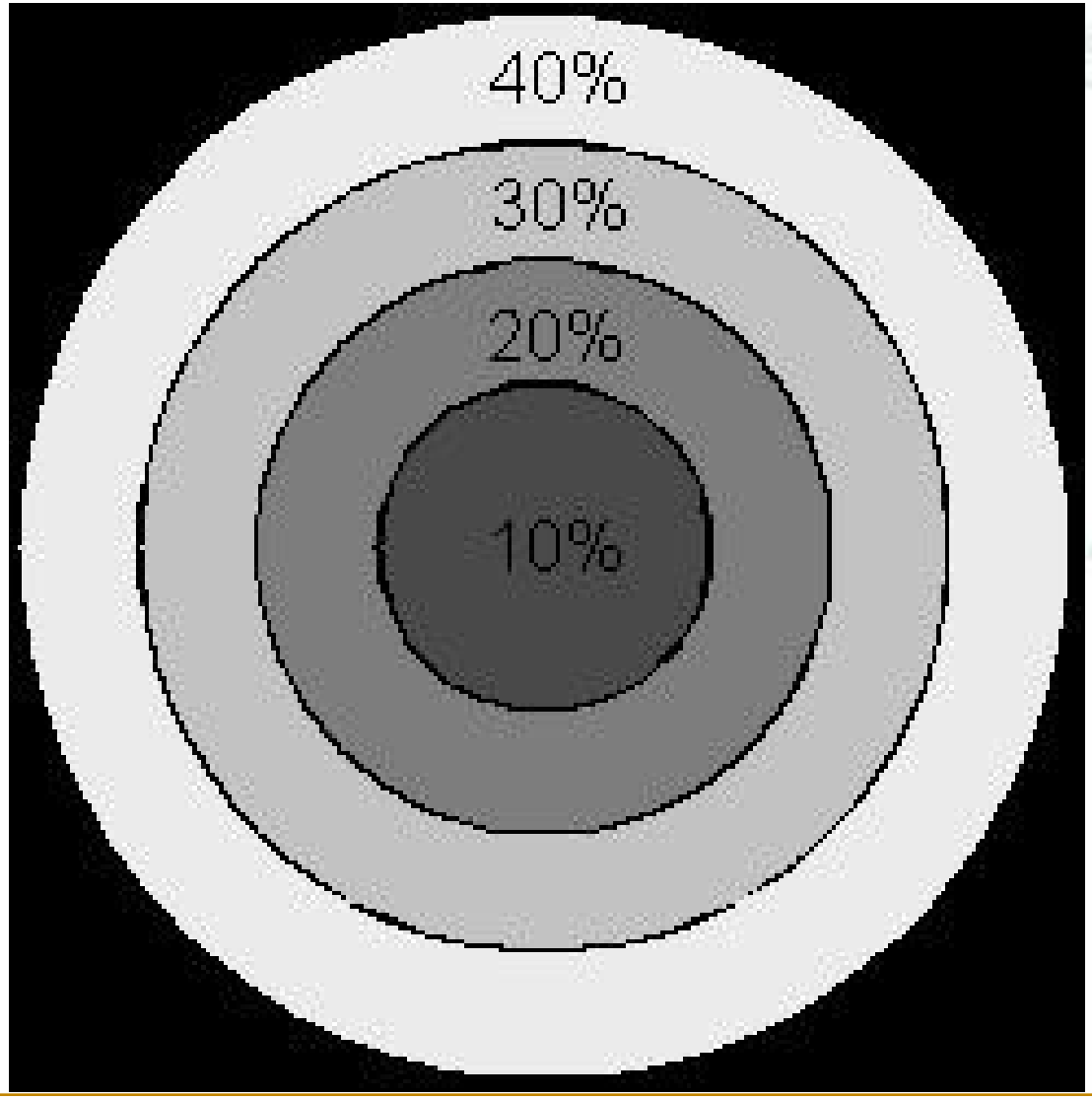


Pipeline Model Approach

For urban area of population X, the model estimates:

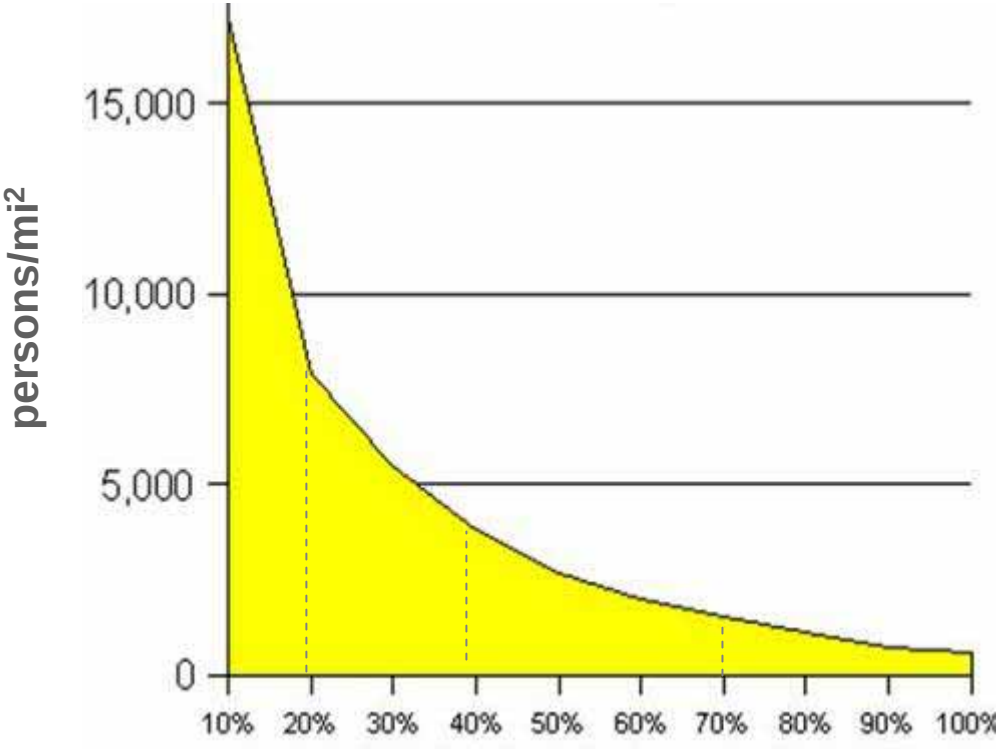
- **Land area and density regions**
  - Population density
  - Density profiles
- **Hydrogen-fueled vehicle density**
  - Density region
  - Vehicle ownership
  - Market penetration
- **Number and location of hydrogen refueling stations**
  - Service ratio (vehicles/station)
  - Minimize service line lengths
- **Pipeline cost and location with respect to centroid**
  - Unit cost by function and diameter
  - Cost minimization heuristic
  - Circuity factors

Urban Land Area Can Be Expressed as a Series of Annular Rings around a Centroid

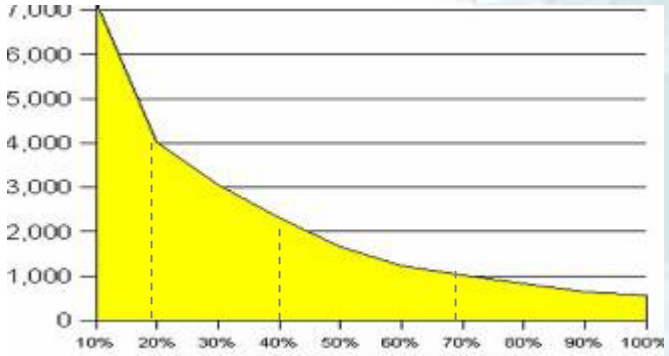


Population Density Declines Asymptotically with Land Area Decile Regardless of Overall Density

San Francisco



St. Louis



Land area deciles

Source: Cox 2004

Vehicle Ownership Is Inversely Related to Population Density

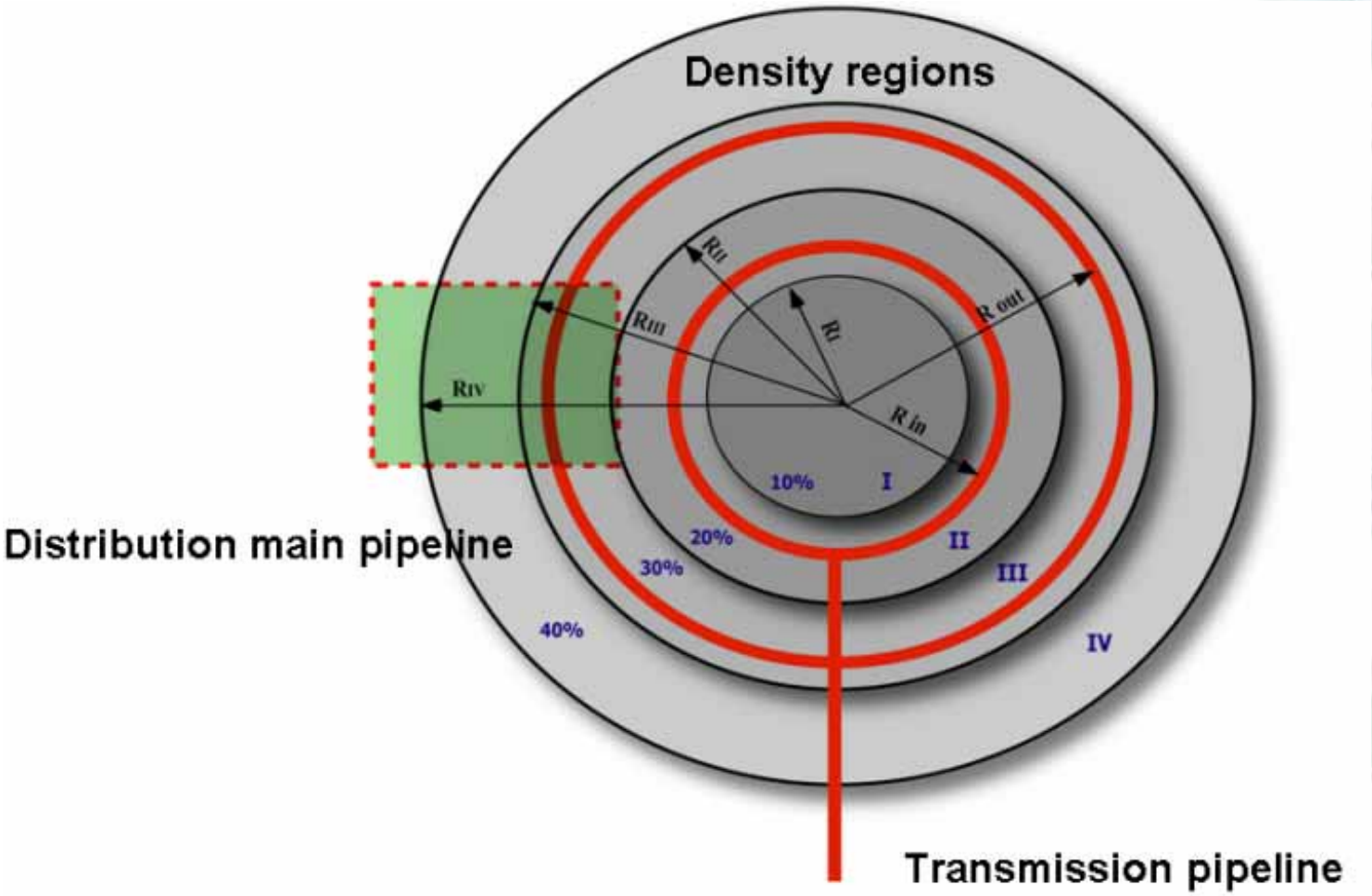
Vehicles per Household	Persons per Square Mile			
	<2000	2000-4000	4000-10,000	>10,000
	Percent of households by number of vehicles			
None	3.9	6.2	8.5	31.0
One	27.3	33.8	38.6	41.7
Two	44.5	42.3	38.6	21.3
Three or More	24.3	17.7	14.4	6.0
Ave. Vehicles	2.9	1.80	1.66	1.05
Household Size	2.51	2.41	2.37	2.33
Vehicles/Person	1.16	0.75	0.49	0.45

Source: NPTS 1995

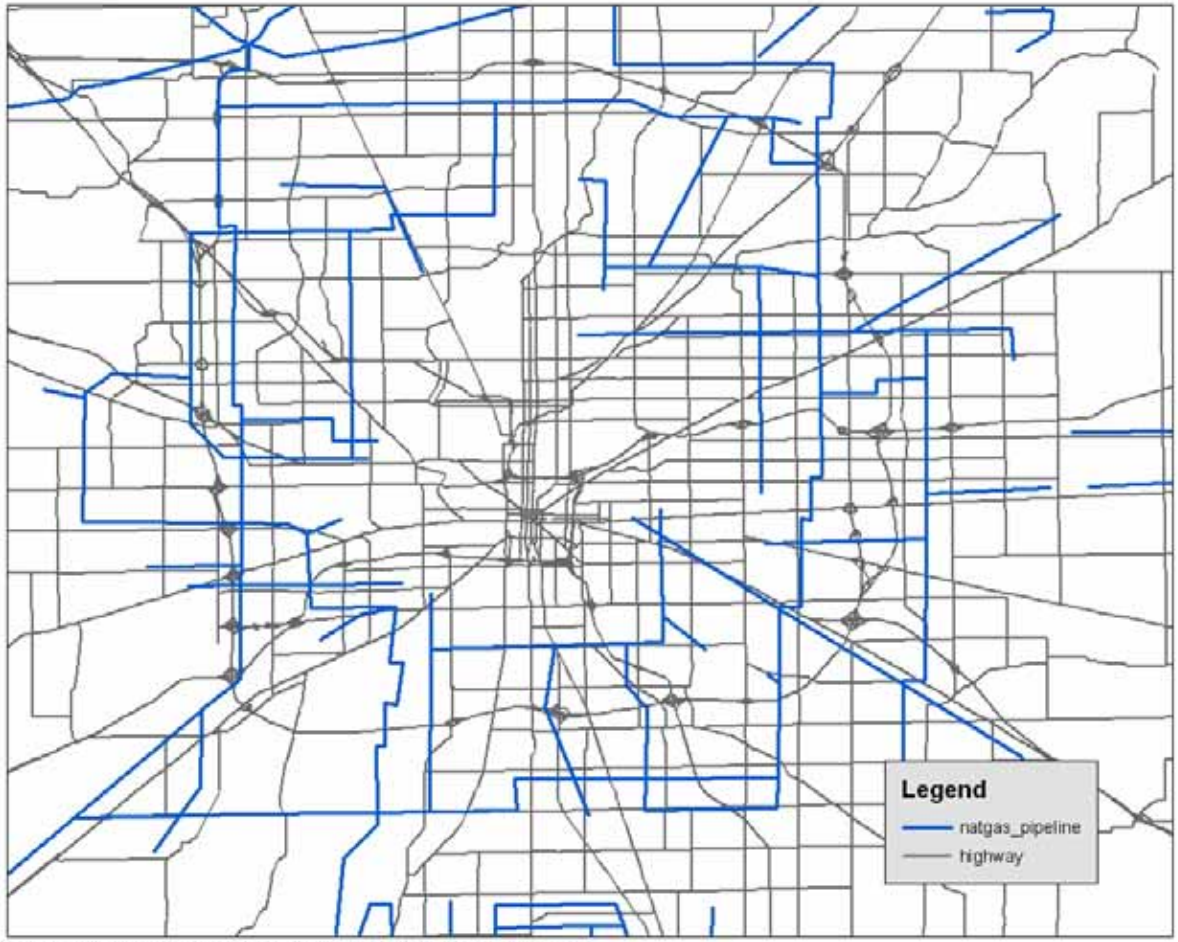
Model Parameters Assuming Moderately Dense Large Urban Area

	Core	1st Ring	2nd Ring	3rd Ring
Outer Radius, mi	3.8	6.6	9.3	12
Area, sq mi	44.8	89.6	134.4	179.2
Density, (persons/sq mi)	7000	3500	1700	800
Population	313,600	313,600	228,480	143,600
Lt Duty Vehicles	154,000	235,000	265,000	167,000
Refueling Stations	77	117	132	83

For Large Urban Areas a Double Ring System (Adjusted for Circuity) Is Least Costly



Indianapolis' Pipeline Geometry Reflects Grid and Radial Highway Network



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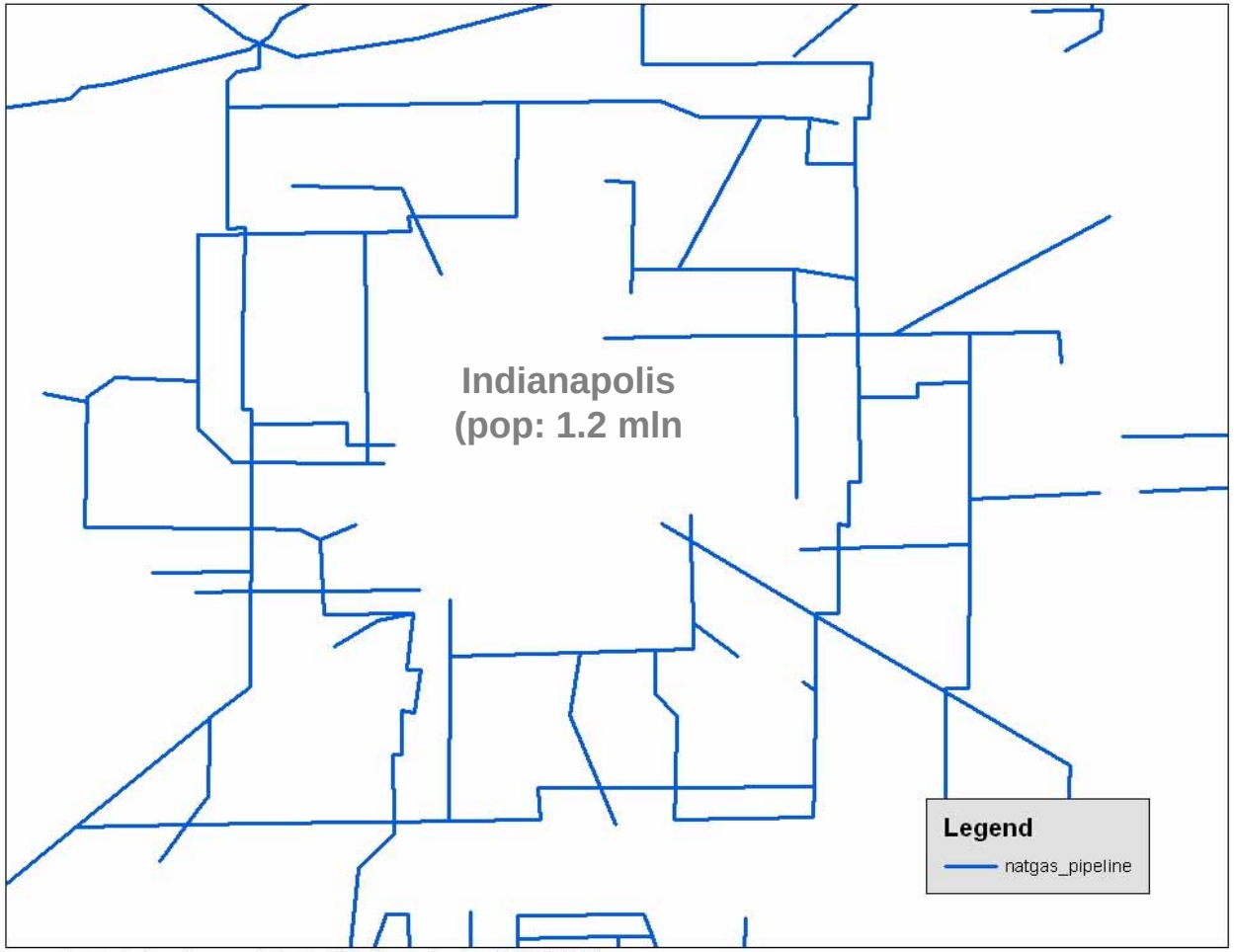
← Beltway ~ 13 miles →

Generic Geometry Compares Well with Observed NG Pipe Geometry for Similar-Sized Urbanized Area



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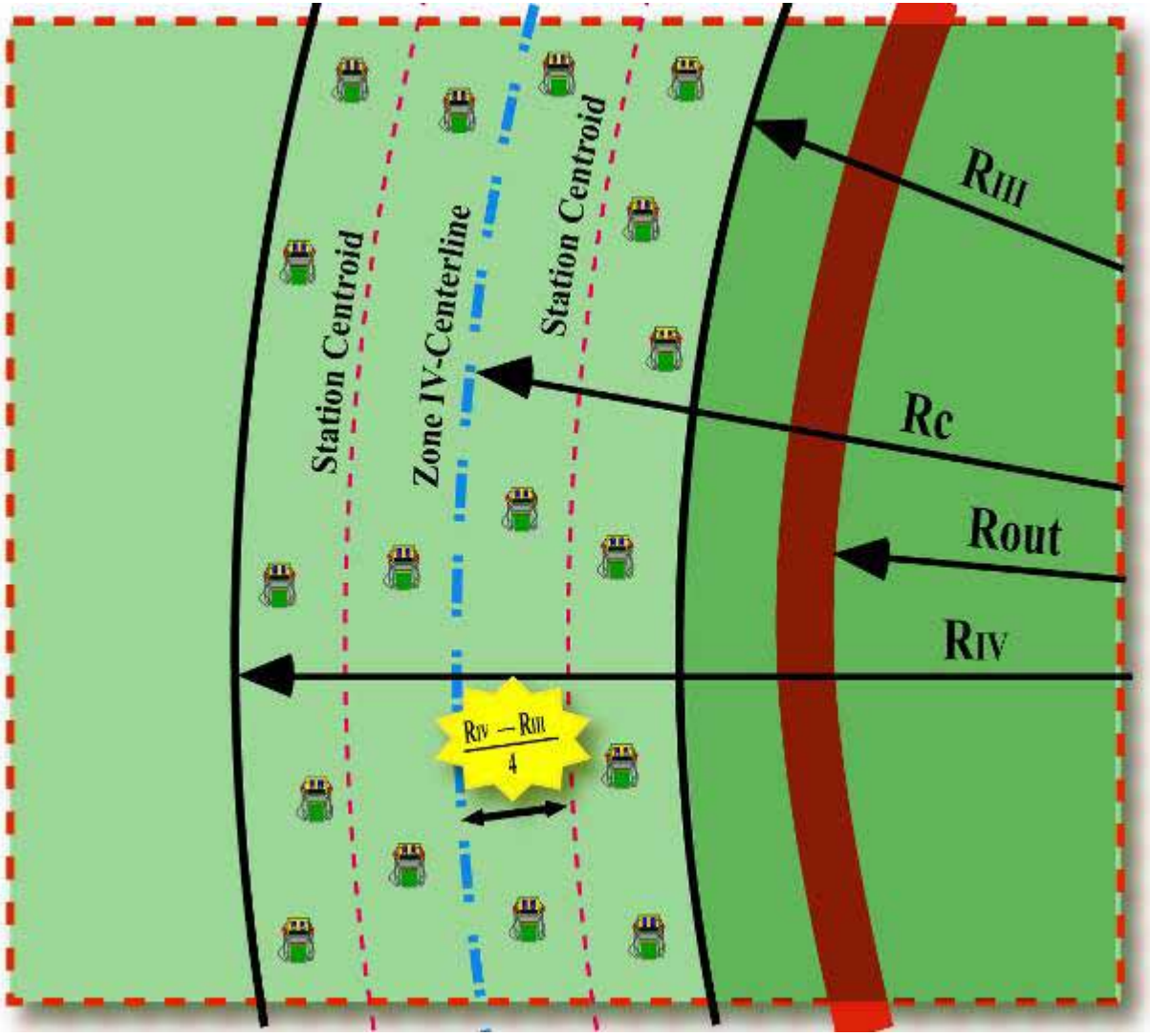
Refueling Stations Are Distributed Around Pipeline Rings to Minimize Service Line Costs

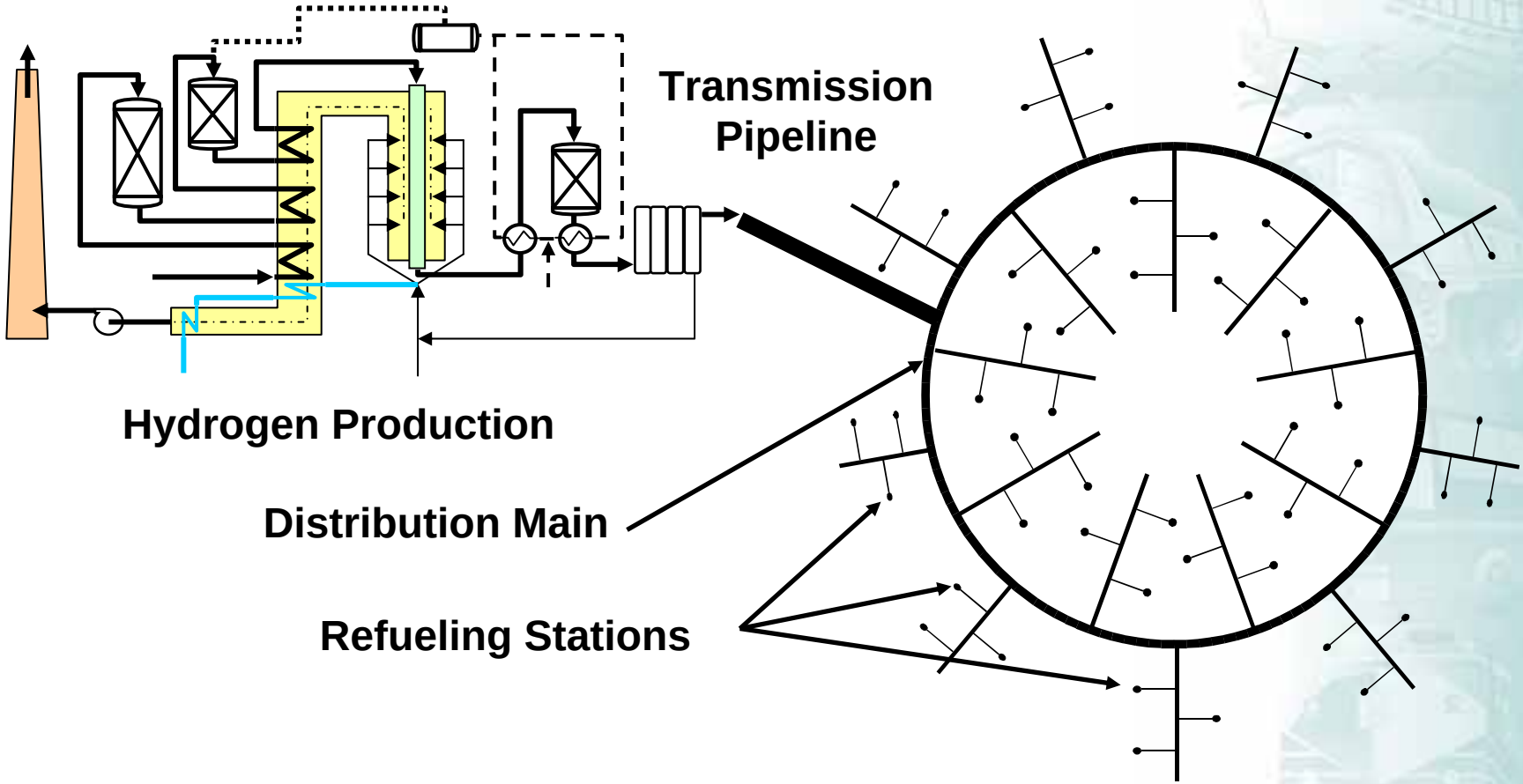


- Rout = radius of outer distribution main ring
- RIII, RIV = radii of 3rd and 4th annular zones
- Rc = radius of zone centerline
- Circuity factor applied to service lines corrects for grid layout

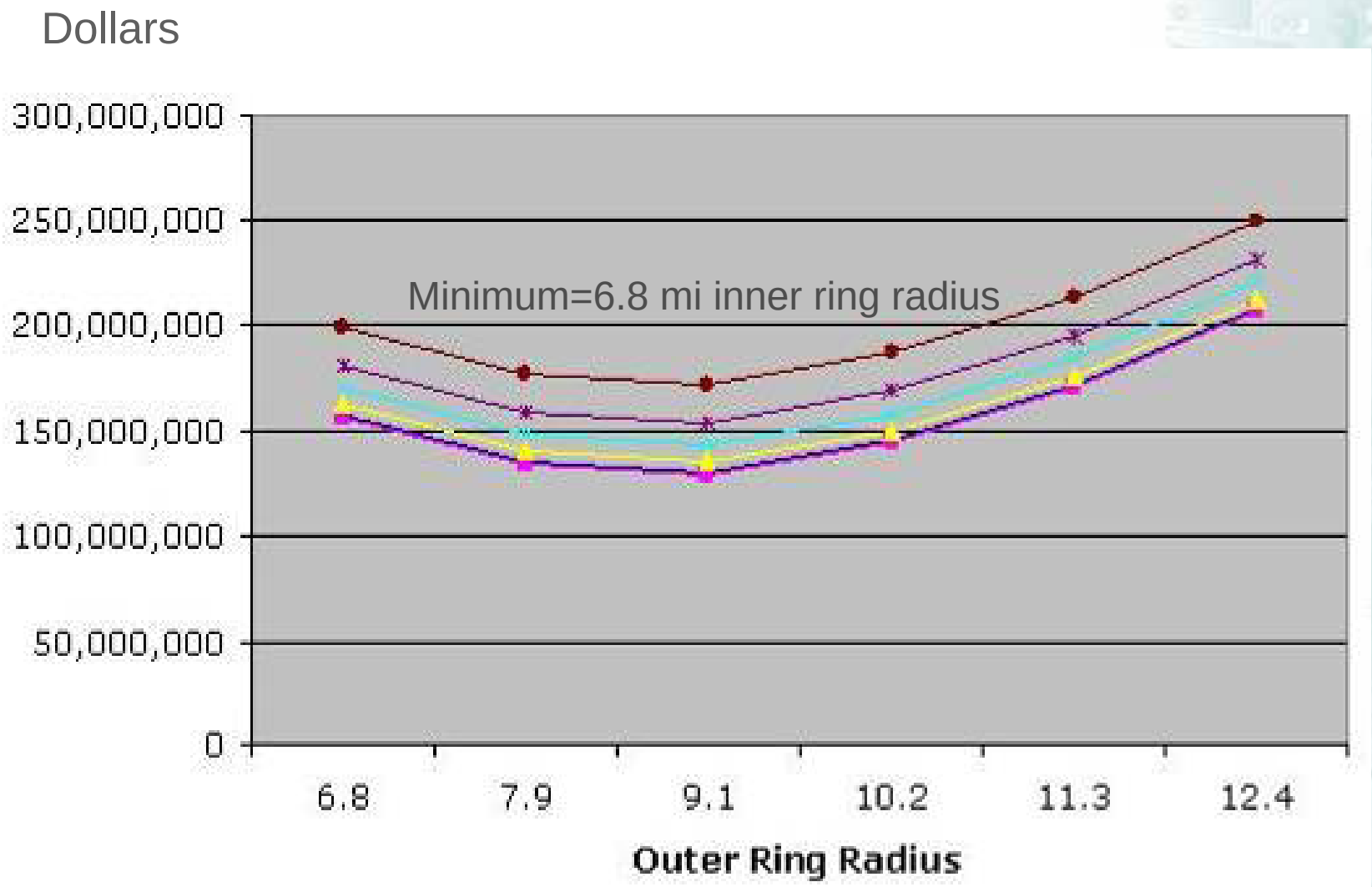
Heuristic Selects Lowest-Cost Locations for Pipeline Mains (Rings) and Service Lines

- Calculates series of ring perimeters and service lines capable of supplying H2 to all stations
- For each set of pipelines, computes capital cost as function of length and required flow rate to satisfy demand (allowing for station dispensing rate and alternative inner pipe diameters)
- Selects lowest cost alternative

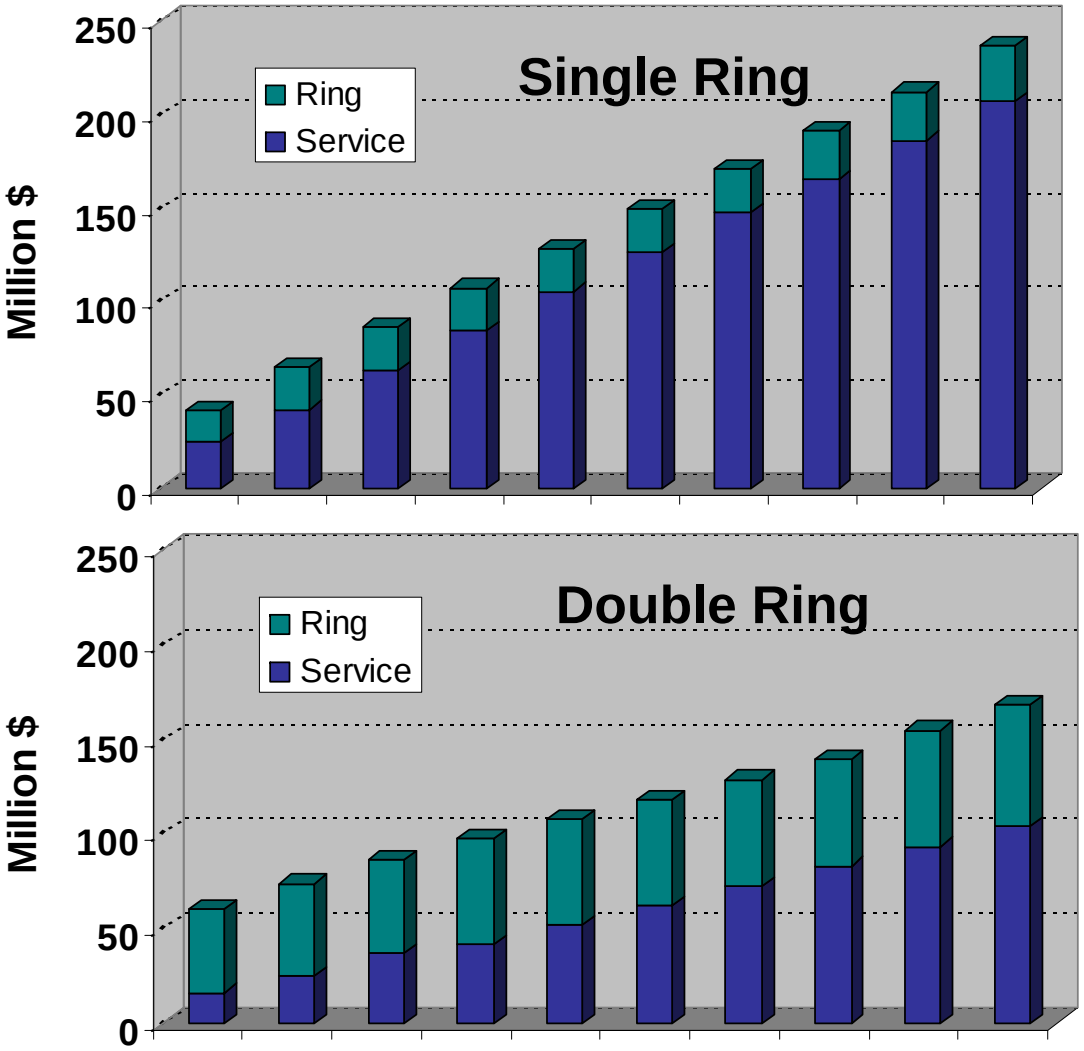
For Small Urban Areas a Single "Ring and Spoke" System (with Circuity) Is Least Costly



Illustrative Output: Least Costly Location of Inner and Outer Rings (70% penetration)



Service Lines Account for Increasing Share of Pipeline Cost as Penetration Rises



- For 1-ring system, service lines account for 60 to 87% pipeline cost
- For 2-ring system, service lines account for 27 to 62%
- 1-Ring system less costly below 30% penetration
- Lowest cost 2-ring mileage achieved at 40% penetration

Current Status and Next Steps

- **Link to Scenario and Components models**
- **"Sketch" networks**
  - Reduce service line mileage
- **Sensitivity analysis**
  - Service ratio
  - Pressure drop
  - Dispensing rate, forecourt storage, etc
- **Tradeoffs**
  - LH_2 truck versus pipeline line-haul
  - 10,000 vs. 5000 psi truck delivery

Thank You!

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